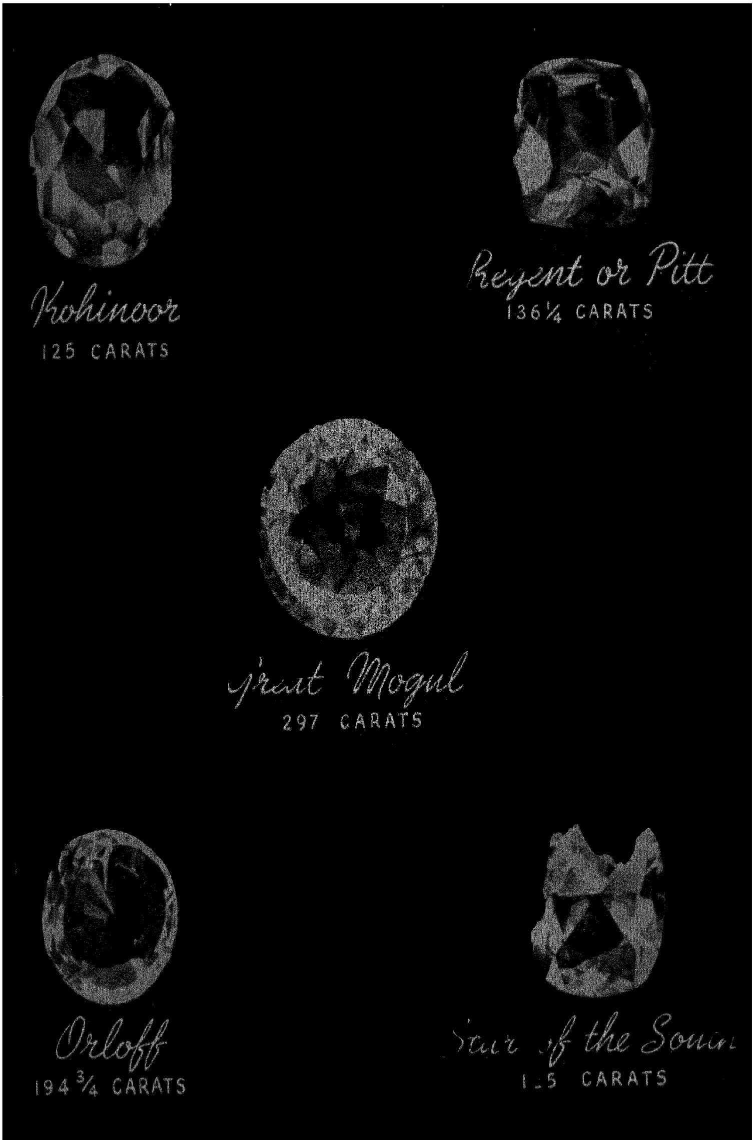
Survey of Physical Science

for College Students



Famous Diamonds. (*Courtesy American Museum of Natural History.*)

Survey of Physical Science for College Students

BY

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PREFACE

THIS TEXT comprises a survey and orientation course in the physical sciences.

In any large group of students who are beginning their college work there will be found three types: students who have had little or no science in preparatory schools and who do not intend to pursue intensive work in the scientific field; students who plan to major in science; students who are potential science teachers in secondary schools. To present vital facts in science to a group of such varied interests is difficult. In this text, an earnest attempt has been made to provide material which is of value to each of these groups, yet material so chosen that there will be little duplication for students who supplement the course with the traditional courses in chemistry, physics, geology, and astronomy.

It is believed that the text will enable those students who will go no further in science to have a better appreciation of their scientific environment. One of the criticisms which is being directed at the science departments of our colleges is that each department aims to train students intensively in a particular field, to the exclusion of the other curricula of the college. No attempt is made in this text to give intensive training. An orientation course, however, does assist the student to choose the field of science best fitted to his needs.

The proper presentation of secondary school science is one of the most difficult tasks that a teacher can undertake. Because of the breadth of the field it is desirable that the teacher have a thorough training in the entire field of science. Realizing this fact, this survey of science has been so built that it provides a physical science background for the potential teacher of general science. To this end numerous elementary demonstrations have been included throughout the text, as well as much thought-provoking material which should serve to stimulate the logical process of scientific thinking which is so necessary to the teacher of science. The experimental exercises found at the end of each chapter are suitable either for classroom demonstration or for

individual laboratory work. In every possible instance, simplicity, both in equipment and in technique, has been sought.

The textual material has been divided into chapters which, as much as possible, are complete in themselves. Although each chapter contains some integrated material, and a continuity of thought connects most of the chapters, most chapters are independent in their presentation. This makes it possible for the teacher to omit chapters and in many cases to change the order of use. Although the book is primarily intended for a three hour course for a year, it is equally useful for a semester course if certain chapters are omitted. It is suggested that chapters 8, 10, 18, 22, 23, 24, and 26 can be omitted without loss of continuity. The variety of chapters enables each teacher to choose the material best suited to individual needs and interests. It is suggested that the text be supplemented by extensive reference reading in books and magazines.

The treatment is, of necessity, rather elementary, and in some cases the explanations are less rigorous than those found in the standardized courses in the various related fields. Some technical interpretations cannot be included in a text of this character. However, scientific principles have not been sacrificed in an effort to attain simplicity of presentation. In choosing the topics for inclusion in the text, the test in each case has been whether a topic is frequently discussed in popular scientific articles in newspapers and magazines. Because of their popular interest, we have devoted paragraphs to such topics as "Polaroid," color photography, infra-red films, and television.

Our thanks are due to Miss Thelma Greenwood and to Mr. J. A. Lewis for helpful collaboration. Dr. C. B. Bazzoni of the University of Pennsylvania has read and criticized part of the text, for which we are very grateful. Mr. Charles Hexter, Jr. has been most helpful in making many of the photographs. We desire to express our appreciation to the Pennsylvania Railroad for material on air conditioning. We also wish to express our appreciation to Jane B. Lewis and Maude B. Newman for their critical examination of the manuscript for faults in English.

PAUL McCORKLE.

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I

INTRODUCTION

To Science, pilot of industry, conqueror of disease,
multiplier of the harvest, explorer of the universe,
revealer of nature's laws, eternal guide to truth.

Inscription on the National Academy of Science.

THE HISTORY AND AIMS OF A SURVEY OF SCIENCE

As we turn back the pages of history, we are rather amazed at the paucity of scientific achievement in early centuries. Although the Chinese and the Greeks made great progress in mathematics, logic, and art, they accomplished little in the physical sciences. One of the great thinkers in the fields of science and logic was the Greek, Aristotle 384–322 B.C. This man wrote voluminously in the sciences and in politics. A master of logical thinking, yet he erred in many of his ideas because he did not use the experimental method as a check on his logical arguments.

There is, however, in this period, one exception in the person of Archimedes, who lived in Syracuse about 250 B.C. This great mathematician also worked in the realm of science. He stated the principles of flotation and of levers so clearly that we cannot improve upon his arguments.

During the period from 200 B.C. to 1200 A.D., there was a long interval during which little scientific work was done. It is true that the Arabs, taking up the torch of learning dropped by the Greeks, did some work in mathematics and alchemy. During this long interval, most of the learning was concentrated in the religious bodies in Europe. It is therefore not surprising that these bodies became the centers of intellectual advancement. Consequently, when Copernicus and Galileo appeared upon the scene, their revolutionary ideas in science had to confront the fixed ideas of the religious leaders. Many persons have severely

criticized these leaders for their refusal to accept quickly these new concepts of the physical world. Perhaps such criticism is not altogether justified. When ideas have been prevalent for centuries, it is difficult for men to throw aside these ideas over night. Even today men change their opinions very slowly.

However that may be, we have in the work of these men examples of the triumph of experiment over pure logic. Galileo is rightly called the "father of experimentation." Whether or not he actually dropped objects from the leaning tower of Pisa, he was the first to actually test his ideas by his sensory impressions. After his time science became a prominent part of human knowledge.

In the very year of Galileo's death, Sir Isaac Newton was born. One of the greatest of thinkers, this man was destined to carry forward both the experimental method formulated by Galileo and the logic of the type used by Aristotle. By careful observation he formulated laws of the universe, which are amazing because of the clarity and brevity of their language. Unfortunately, it often happens that the ideas of a great thinker hinder progress in later generations. This was the case with both Aristotle and Newton. Some of Newton's statements, especially in the field of light, were incorrect. But such was his prestige that not until 1801 were they successfully challenged. When Thomas Young in that year proposed the wave theory of light in contradiction to the corpuscular one of Newton, men at first ridiculed his suggestion. But again experiment had its way and thus was opened a great new field of investigation.

Other scientists of this period were Franklin, Hutton, Volta, Laplace, Lavoisier and Davy.

After 1800 the progress of science was rapid and extensive. We must be content to mention merely a few of the great investigators of the 19th century. Some of the outstanding names are Foucault, Michelson, Herschel, Kirchoff, Priestley, Fraunhofer, Dalton, Tyndall, Wöhler, Maxwell, Mendeleeff, Hertz, Helmholtz, Kelvin, Faraday, Arrhenius, Agassiz and Darwin. Many of these men will be introduced to the reader in later pages as we proceed in our study of science. A sincere student of

the scientific method will feel impelled to read the biographies of these great men in which are revealed the scientific methods of approach to the great problems of the universe.

Today the progress of science is so rapid and its achievements so vast that we dare not be dogmatic in our thinking. The accepted theory of today may be outmoded by the experiments of tomorrow. In the hands of such men as Roentgen, Richards, Thomson, Rutherford, Millikan, Urey, Einstein, Compton, Bohr, Sommerfeld, Nieuwland and Heisenberg, to name only a few, our world of science has been rapidly expanding. No one can foresee the progress of the next generation.

This is an age of science. We are masters of machines. The man on the street ridicules the routine laboratory man and the theorist, but at the same time holds up to reverence an Edison or an Einstein. Such is the fame of Einstein that any item concerning him is important news. The entire text of the paper presented by Einstein in 1926 to the Prussian Academy of Science was cabled to the *New York Herald Tribune*, and was published in its entirety, including mathematical equations so complicated that only a few mathematical specialists could read them intelligently.

Although he is disdainful of the methods of the scientist, the layman is quick to capitalize on the results of his achievements. Many a man has invested his fortune in a new wireless patent, or a dreamer's method for television. Newspapers will still give space for an announcement of a "fuelless" motor, a "perpetual motion" machine, or "creation of life" in a test tube. Texts on popular science are best sellers. (One wonders just how much the layman understands of a popular description of the theory of relativity even when written by a master.)

Ignorance of science leads intelligent people into ridiculous decisions. Some years ago a great hubbub was created by a principle called *technocracy*. One fallacious idea which came out of the principle was that science should stop making new discoveries of labor-saving machines lest mankind perish from economic bankruptcy. On the medical side, witness the millions of magnetic belts and other worthless contrivances and "patent" medicines which man buvs to cure his ills.

For generations, men have accepted the doctrine of cause and effect, and only in the last decade has the principle been called into question. During some periods in the world's history the doctrine produced curious conclusions. The Greeks believed that a man's life was charted at birth. If, for example, the individual was destined to die by drowning, it was beyond his power to prevent the accident. Such ideas were carried over into religious beliefs by Calvin and others, and led to the doctrine of predestination as opposed to that of free will. In science, men believed that if one could discover all the laws which govern a certain phenomenon, one would be able to understand the course of the experiment, be it the eruption of a volcano, a radio broadcast, or the flash of a lightning discharge. Perhaps one might state the position as that of law and order. They believed that the universe was originally "wound up" and started on its path according to a set of physical laws. To know these laws would be to know truth. Today, many thinkers believe in a doctrine of free will (chance) in the field of physics and other sciences.

The thinking individual sees the world about him and speculates about its reality. Science attempts to describe and interpret the universe for him. It makes known that the universe has had a long period of evolution; it has gone through great changes in form and character of life. Unfortunately, the layman often translates this into the "monkey-man" delusion and shrieks that such ideas are blasphemy. Most men are content to enjoy the benefits of science and they make no attempt to advance its boundaries. Occasionally there arises a mental giant who with one vital principle takes science ahead to great new discoveries. As these men come upon the stage of human progress, science advances by great strides.

Many persons have seized upon this realization of a scientific age to insist that the scientist must come down from his pedestal and scatter his knowledge to all men. To this end some educators insist that survey courses in science must be superficial in character. Their viewpoint is that most persons are merely "tourists in the forest of science and not hewers of wood." This type of argument has won many friends among those to whom concen-

trated thinking is abhorrent. As long as a beautiful word picture is drawn concerning an atom, they do not wish to be compelled to search underneath the painting for the artistry of the painter. We read in our newspapers about such apparently unrelated items as X-rays, radium, cosmic rays, and cancer cures. It is the goal of science to coordinate such experiences, so that the intelligent man may be able to have a logical understanding of the underlying principles. This idea has been well stated by Einstein when he says "The object of all science is to coordinate our experiences and bring them into a logical system."

In order to accomplish this end, a survey course must strive to integrate the sciences to such an extent that the student sees the interrelation of all knowledge. However, in accomplishing such integration we must be careful not to substitute slipshod thinking for exact logical processes. Clear thinking is always more satisfactory than half truth. In early times there was only natural philosophy. Man had not set up the arbitrary subdivisions of physics, geology, astronomy, biology and chemistry. Although our scientific knowledge has greatly increased during the past century, it is still possible and wise to continue to introduce science by teaching natural philosophy.

There is also to be considered the use of a survey course in science as a cultural subject. Many a college graduate has a thorough knowledge of the works of Shakespeare, but he has no intelligent information concerning the method of lighting the home. Moreover, such students have acquired no information or appreciation of the techniques and skills which the scientist has developed over a long period of years. It should be the function of the course to give all students some cultural information. A natural result of such a survey is a desire on the part of the student to continue his studies along scientific lines. To appreciate science one must have a background of scientific knowledge. A good survey course should stimulate the reader to further progress in the field of science.

The student may forget much of the factual material learned in his science courses; but, if he is an intelligent thinker, he will acquire from his science training the ability to judge values both

in people and in material things. He will not be led astray by half developed theories. He will be prone to sift ideas and to reserve judgment concerning questionable proposals. He will have learned to think logically and accurately. The modern industrial life is a very complex and intricate network. Today, each of us is a link in a great chain and the trained mind is essential to success.

Anyone who attempts to survey any field of science is faced with certain fundamental problems. During the past century the world has seen a tremendous output of new marvels which have had their origin in the work of some scientist. The scientific world is in a state of flux. The astronomer has penetrated far beyond the limits of the universe of our ancestors and is speculating about the size of the universe of stars and nebulae. The chemist is building up synthetic products at such a rate that the whole world of human affairs seems to be dependent upon the laboratory. Within the past twenty-five years scientific discovery has awakened the mind of man to the realization that we live in a very complex universe of which our world is only a tiny but very complicated fragment. Despite this advancement there is not one single branch or even a minor subdivision of which we can write a compilation of all that is known and say "this is the final record." Science has made and will continue to make for us a better and more comfortable world. It remains to be seen whether man can adjust his social structure to avail himself of the great advances offered as a result of scientific research.

The student who begins the study of the physical sciences may be appalled by the size of the task before him. He must remember, however, that in science as in all other fields of knowledge, it is necessary to acquire a vocabulary of technical terms. Only by repeated use of these technical terms can one hope to acquire the vocabulary necessary for scientific development. Moreover, this is an age of experimentation and research. It is to be hoped that the student will, if possible, avail himself of considerable laboratory experimentation. Only by such methods can one really appreciate the scientific method.

The educational value of a study of science consists not so much in remembering the statements of others as in forming individual opinions through study and experimentation. The student who is satisfied to fill his mind with facts in order to pass an examination will not progress far in scientific thinking. He should learn to read and write intelligently on scientific topics. A good teacher of science will rely less on memorized facts than on a careful interpretation of the physical phenomena which the student experiences in daily life. An understanding of the principle of the doorbell is far more important than a memory drill on the Laws of Motion.

The student must always remember that the field of science is too vast to be adequately covered in any elementary textbook. What is learned from a survey of science is only a stepping stone to a fuller realization of the tremendous activities of scientific investigators. Although much of the material in the book is well established, many statements made at present will need revision in the light of later study. Above all, the student of science must not be content with slipshod statements. It is just as easy and far more satisfactory to state principles accurately as to make vague statements which really mean nothing.

Although in a survey of science it is necessary to discuss most topics rather briefly, the earnest student should be able to find plenty of reference material, both books and magazines, in libraries and on news stands. It is hoped that students of science will form the habit of reading widely, not only in science but in all fields of knowledge.

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2

THE SUN

"Girt with his mantle of tempestuous flame
glares in mid heaven; but to his noontide blaze
The slender violet lifts its lidless eyes
and from his splendour steals its fairest blue
Its sweetest perfume from his scorching fire."
Holmes

MAN HAS always wished to understand the reasons for the phenomena of nature which he noticed about him. Those things which he did not understand he often made a part of his religious worship. The eclipses of the sun were thought by the Chinese to be caused by a dragon swallowing that life-giving object. The priests beat drums to drive away the dragon. Many peoples sacrificed human life in sun worship. Early man was a hunter and a fisherman and he wove the animals around him into his religion and into his ideas of the sky. Later he became a herdsman, and his religion contained a worship of pastoral things.

At a very early time the idea took root that the stars and the planets were controlling factors in man's life. Because of this, the subject of *astrology* became important in the minds of men. Much of our knowledge of early peoples is due to the fact that they recorded eclipses and other happenings in the heavens.

Perhaps the most reverenced of all bodies was the sun, the "day star." This was most natural, inasmuch as life itself depended on the sun. The Egyptians and the Chaldeans made the sun one of the supreme gods. Consequently, in beginning a study of physical phenomena, it is natural to first consider the sun, for our sun is certainly to us the most important of all heavenly bodies. We, too, are dependent upon it for life itself. It provides light, heat, ultra-violet, and makes possible the growth of plants by a photo-chemical process (see p. 385).

Our sun is an intensely hot ball of gas and liquid that shines by its own light, as contrasted to the planets, such as Mars, which shine by reflected sunlight. It is a star of average size and temperature. Betelgeuse in Orion is 400 times the diameter of the sun.

Since, compared to other stars, the sun is close to the earth, it appears to us to be a very large body. Actually, the sun is about 93,000,000 miles from the earth. To form a concept of this distance, imagine an aviator flying toward the sun at a speed of 300 miles per hour. He would need 40 years to travel the distance. The diameter of the sun is 866,000 miles, which means

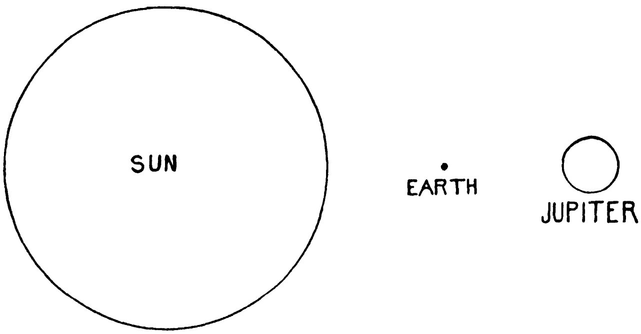

FIG. 1.—Comparative sizes of sun, earth and Jupiter.

that it is about 100 times the diameter of the earth. (Fig. 1.) It requires 8 minutes for sunlight, at a speed of 186,285 miles per second, to travel from the sun to the earth.

The outermost part of the sun is called the *corona* (Fig. 2). This is visible only during a total eclipse, at which time it appears to be a great, irregular globe of a pearly white color. It apparently consists of a very much rarefied gas extending out several hundred thousand miles. The exact constitution of the corona is still in dispute, but it is quite certain that it contains no unknown elements. Within the corona lies the *chromosphere* (color layer), a layer of gas mostly hydrogen, 5000 miles thick. It is in violent motion and at times shoots out great prominences (Fig. 3) of glowing gas as much as a million miles high. The gases of the chromosphere are also responsible for the *Fraunhofer lines* (see

p. 19). The central part of the sun, the visible disc, is named the *photosphere* (light-giving sphere). The temperature of the center of this photosphere is believed to be several million degrees, and

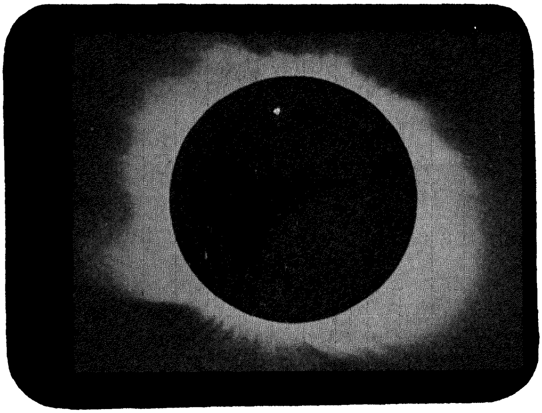

FIG. 2.—The corona. (*Weld and Palmer.*)

the temperature of the surface is known to be about 10,000 degrees Fahrenheit. This is far hotter than any temperature on

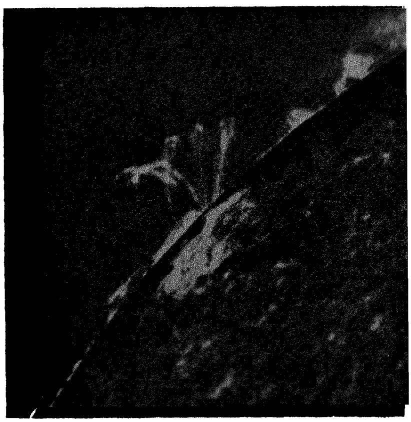

FIG. 3.—Solar prominences. (*A reprint of Yerkes Observatory negative S95. By permission of the University of Chicago Press.*)

the earth. Because of the enormous pull of gravity on the sun, the material in the center is compressed very greatly, and this results in the mass of the central part being very compact.

Rotation. The sun rotates on an axis in the same direction as the earth rotates. The time of rotation varies at different points, being 25 days at the equator, and 33 days near the poles. Such a motion indicates that the sun is a fluid.* The evidence for this rotation is based on the Doppler principle. Everyone has noticed that the pitch of the sounding horn of an automobile seems to rise as the car approaches and to fall as the car recedes. The principle

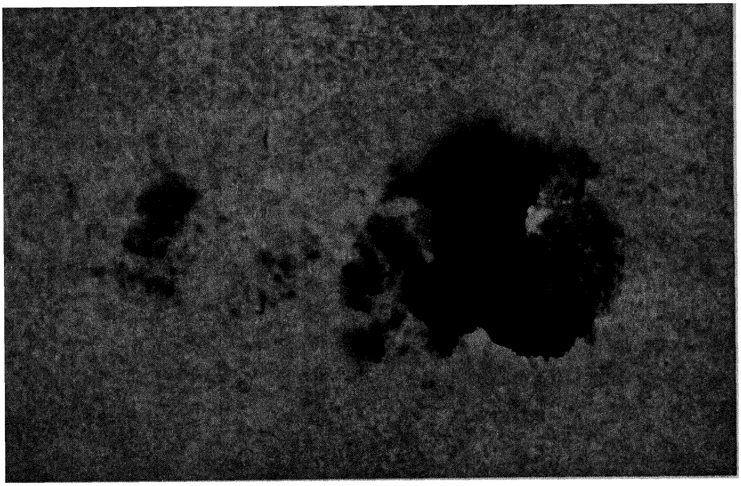

Fig. 4.—Sun spots. (*Mt. Wilson Observatory.*)

as applied to light states: If a luminous body moves rapidly toward us, the color of the light seems to shift slightly toward the violet end of the spectrum, the shift depending upon the speed. If the light source is moving away from us, the color shifts toward the red. From an examination of the two sides of the sun's disc, the spectroscope indicates the rotation. Sun-spots (Fig. 4) also aid in proving the rotation of the sun.

The position of a line in the spectrum is indicated by its wave length. For example, the red line of hydrogen under normal conditions has a wave length of .00006563 cm. If the light of a receding body is examined, the wave length of the line will be found to be slightly longer. If the body is approaching, the wave length seems to be somewhat shorter. The apparent change in wave

* A fluid is a gas or a liquid.

length is due to the body's motion and not to any change in the state of the substances emitting the light.

Sun-Spots. These spots are dark areas, some more than 50,000 miles in diameter, and are really saucer-shaped valleys on the surface, consisting of whirling masses, or spinning funnels of cooler gas which constitute cyclonic storms (see p. 161). A vortex or whirlpool in water, such as is caused by a canoe paddle, is a good illustration. Some of the sun-spots occur near the equator of the sun. Hale, an astronomer at the Mt. Wilson observatory, in 1906 discovered that these sun-spots produce intense magnetic fields and that the Zeeman effect (the splitting of spectral lines by

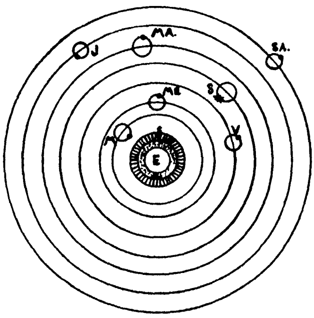

Fig. 5(a).

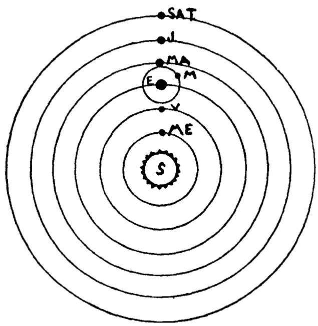

Fig. 5(b).

Fig. 5(a).—A diagram of the Ptolemaic universe.
Fig. 5(b).—A diagram of the heliocentric universe.

a magnetic field) was visible in the whirling spots. These sun-spots become numerous at intervals of about 11 years. They were numerous in 1926, and again in the years 1937 to 1939. It has been known for many years that at a period of sun-spot activity we have magnetic storms which disturb radio and telegraph service. At such times the aurora borealis (see p. 318) is very prominent. There is at present no satisfactory explanation of the cause of sun-spots.

Appearance of the Sun. The casual observer will, however, not find much of interest in the sun. It appears to be a ball of yellow fire, too bright to be gazed at directly. We notice that it is high in the sky at noon in the summer, and that it is low during the winter months. We also are aware that it gives us long days in

summer and short ones in winter. Most people also know that an exposure for a photograph is short when the sun is shining. The sun *apparently* rises in the east and sets in the west as a reddish ball. During most of the day it has a yellow color. Because of this apparent rising and setting, ancient peoples believed that the sun revolved about the earth. (*A revolution refers to the motion of one body about another; a rotation refers to the turning of a body on its axis.*)

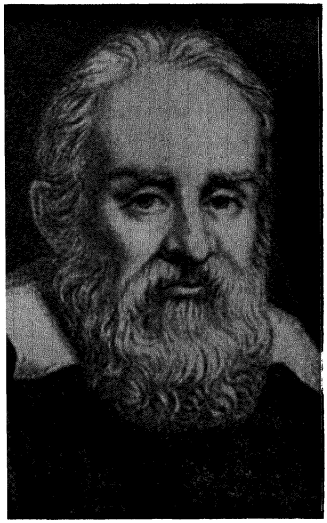

FIG. 6.—Galileo Galilei (1564–1642). Discovered the moons of Jupiter; made one of the first telescopes; discovered the laws of the pendulum; founder of experimental physics.

EARLY ASTRONOMERS

Perhaps the most important scientist of early days was *Aristotle* (384–322 B.C.). This investigator studied biology, astronomy, and many other related fields. His ideas were prevalent until the 15th century. Another representative of the period was the astronomer, *Ptolemy*, (about 100 B.C.). Both of these scientists believed that the earth was the center of the universe. All other bodies revolved about the earth. (Fig. 5.) Little was done until the 16th century, when *Copernicus* and *Galileo* (Fig. 6) advanced the theory that the sun was the center of the solar system, and that the earth and the other planets revolved about it. Galileo, who is often called the "father of experimentation," made a small telescope, and by its use discovered the moons of Jupiter, the phases of Venus, mountains on the moon, and sun-spots. After the time of Galileo the idea of a heliocentric system of planets became a fixed principle in science.

Galileo (1564–1642) was a famous Italian, professor at the University of Padua. He made one of the first telescopes, advocated the heliocentric theory of Copernicus, but because of his irascible attitude was challenged by various religious groups. Because of this attitude he suffered many hardships in his

later life. Some of his discoveries in other fields were the laws of falling bodies and the laws of the pendulum.

It is interesting for us to attempt to understand the attitude of the people of that time. An astronomer of the time of Galileo expressed himself as follows: "There are seven windows in the head, two nostrils, two eyes, two ears, and a mouth; so in the heavens there are two favorable stars (Venus and Jupiter), two unpropitious (Mars and Saturn), two luminaries (sun and moon), and Mercury alone undecided and indifferent. From which we gather that the number of planets is necessarily seven. Moreover, the satellites of Jupiter are invisible to the naked eye, and therefore can have no influence on the earth, and are consequently useless, and therefore do not exist."

ASTRONOMICAL INSTRUMENTS

The Telescope. By means of the telescope, observers are able to study the surface of the sun. If a piece of dark glass is placed in the telescope as a protection for the eyes, we can see that the surface is mottled, and we can study the sun-spots that are sometimes present on the surface. By the use of the telescope we can measure the distance to the sun and, if the spectroscope is added, the constitution of the sun's atmosphere can be investigated.

The telescope is perhaps the greatest of all astronomical tools. Fundamentally, it consists of an objective lens and an eyepiece lens. In the case of an astronomical refracting telescope, both of these are convex lenses (thicker at the center than at the edge). The objective lens is made with a large diameter (Fig. 7a). In the reflecting telescope, the objective lens is replaced by a large concave mirror (Fig. 7b). The 100 inch mirror telescope at Mt. Wilson is of this type. There is being constructed at present a telescope having a mirror 200 inches in diameter (Fig. 8), which will be a part of the most powerful telescope in existence.

The 200 inch telescope was designed by Dr. Hale of the Mt. Wilson observatory near Pasadena, California. The great mirror was cast from a special pyrex glass by the Corning Glass Works. At present, technicians are grinding the glass to the curvature

necessary for use. It is believed that the operation will require several years. The mirror will be coated with aluminum instead of silver in order to secure better reflecting power for the ultra-violet. There are about 60 large telescopes located in the various

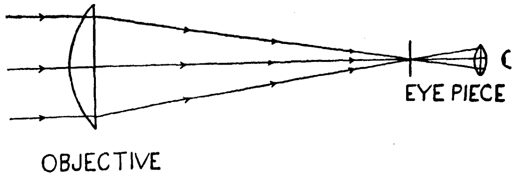

FIG. 7(a).—A refractor.

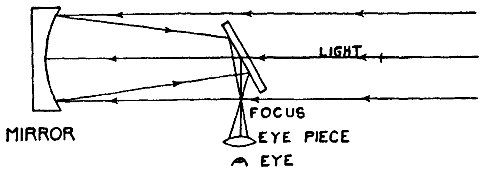

FIG. 7(b).—A reflector.

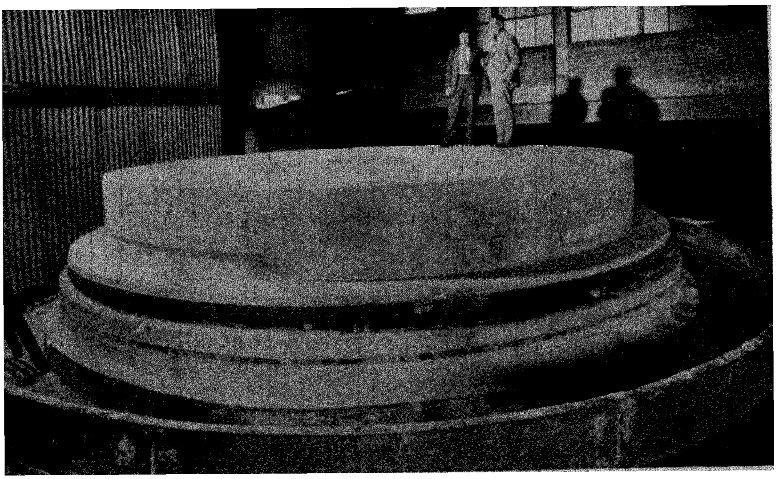

FIG. 8.—The casting for the 200 inch telescope mirror. (*Courtesy The Corning Glass Co.*)

observatories of the world. Figure 9 shows the reflector and the refractor at the Franklin Institute in Philadelphia.

If one wishes to study faint objects in the sky, the large lens or mirror gathers considerable light and brings the light to a focus

for use by the eyepiece or by the spectroscope. Few persons have a clear understanding of the real value of a telescope. If one remembers that the eye pupil is less than ½ inch in diameter, it is evident that the 200 inch mirror will gather about two hundred thousand times the light that the unaided eye can gather.* In this way, stars too faint to be seen by the unaided eye become visible. In addition, the eyepiece has the property of producing an enlarged image, so that the telescope serves the purpose of

FIG. 9.—Telescopes at the Franklin Institute, Philadelphia Pa. (*Photo Gladys Müller.*)

gathering more light and of making some objects such as the *planets* appear larger. (A star is always a point of light.) In order to make the telescope capable of clear vision, much care is needed in grinding and correcting the glass surfaces. The 200 inch mirror is to be ground to an accuracy of one millionth of an inch over the entire surface. The finished mirror will weigh 16 tons, and the completed telescope will cost about 6 million dollars.

THE SPECTROSCOPE. Next in importance to the telescope is the spectroscope. The principle underlying this instrument was discovered in 1666 by Newton (Fig. 10), who formed a spectrum

* The light gathering power depends on the area of the objective.

by passing white light through a prism. This spectrum is similar to the rainbow formed by water drops in the atmosphere. The apparatus was improved by Fraunhofer and others, until it is today a very accurate instrument.* One type of the instrument consists primarily of the triangular glass prism (Fig. 11). When a narrow beam of white light, such as that coming from an electric lamp filament or from the photosphere of the sun, falls on the prism, the emergent light spreads out into a continuous spectrum (Fig. 12). To improve the sharpness of the spectrum we use the lenses. If, instead of white light, the light from sodium vapor or the light of a neon sign of the type used for advertising purposes enters the prism (Fig. 13), the emergent light will consist of lines of discrete colors called a line spectrum (Fig. 12). There will be no "rainbow." We find that *every element in the gaseous state* can produce a group of lines which serves to identify the element, and it also appears that *no two elements ever produce lines at exactly the same place in the*

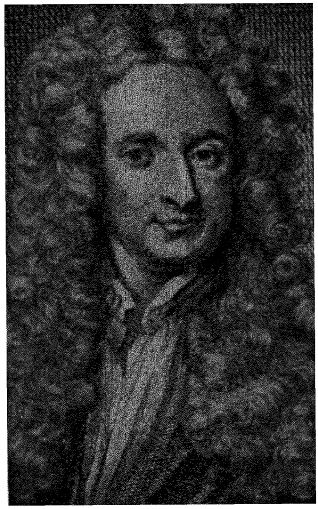

FIG. 10.—Sir Isaac Newton (1642–1727). Invented the calculus; discovered many of the laws of light; stated the law of gravitation. One of the greatest scientists of all time.

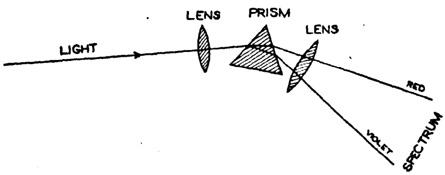

FIG. 11.—Diagram of the prism spectroscope.

spectrum. For example, sodium produces a double line which absolutely identifies the element (Fig. 12). If sodium chloride (table salt) is placed in a flame, an amount as little as one one-

* See note, page 205.

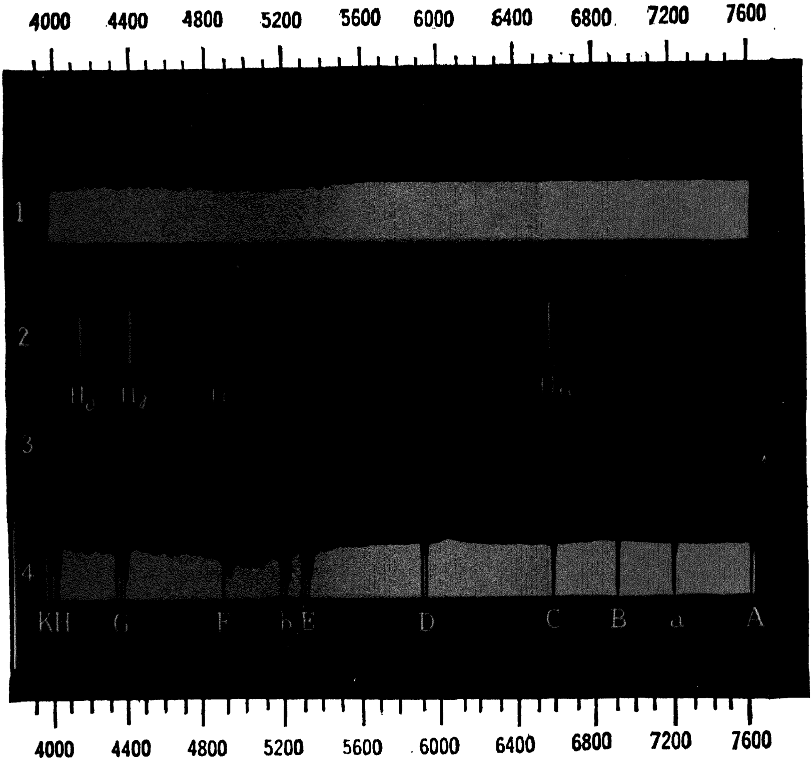

FIG. 12.—(1) Continuous spectrum; (2) line spectrum of hydrogen; (3) emission spectrum of sodium; (4) solar spectrum, showing absorption or Fraunhofer lines. (*From Duncan's, "Astronomy," Harpers and Bros.*)

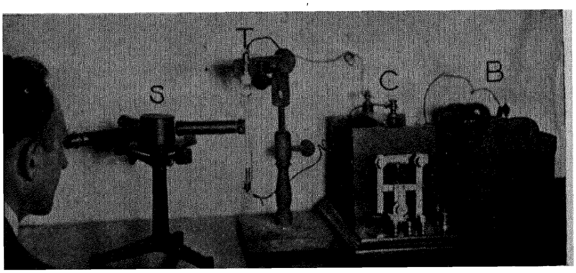

FIG. 13.—Viewing the bright line spectrum of helium by means of a spectroscope. C is an induction coil which supplies current for lighting the helium tube T which contains helium gas at low pressure.

hundred thousandth of a milligram can be detected, so that the chemist may use the spectroscope for analysis.

However, when we use the spectroscope to study the sun, we find a continuous spectrum upon which are superimposed a great many dark lines, called after the discoverer, the Fraunhofer lines. (Fig. 14.) (At the time of a total eclipse, when the photosphere is

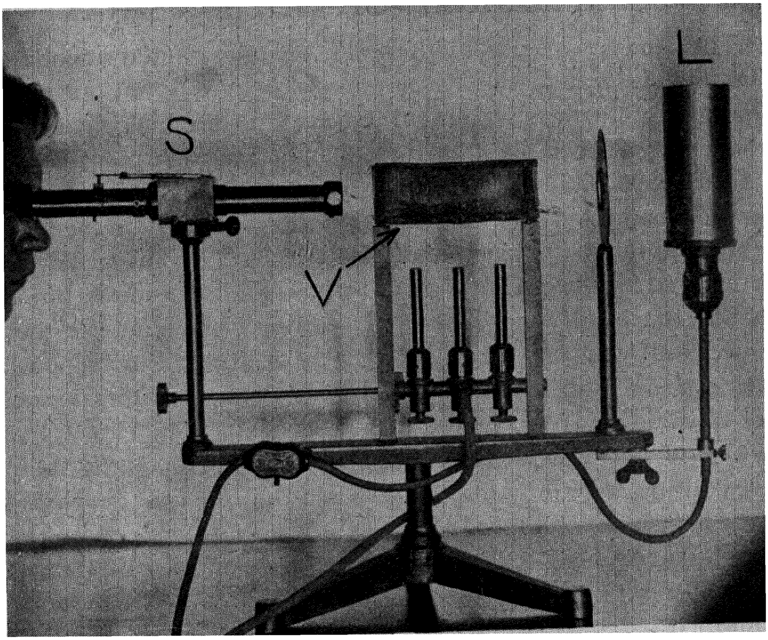

FIG. 14.—An apparatus which illustrates the principle of the Fraunhofer lines. L is a tungsten lamp which represents the photosphere; V contains sodium vapor, representing the chromosphere. The sodium lines are viewed by the spectroscope S.

covered, the Fraunhofer lines become bright lines, called the flash spectrum.) By means of the spectroscope, it has been found that 61 of the 90 known elements certainly exist in the chromosphere of the sun. However, the most striking result is that no evidence has been found that any element is present which does not exist on the earth. Possibly, the reason that some of the other 29 elements have not been found is that they lie deep in the sun and do not occur in its atmosphere (chromosphere).

The spectral lines of 12 of the missing elements are principally in the ultra-violet, and the rays do not penetrate the earth's atmosphere. (The element helium was first discovered in the sun by means of the spectroscope.) Some important elements which have not been found in the sun are: gold, mercury, bismuth, radium, cesium.

POSSIBLE SOURCES OF THE SUN'S HEAT

The sun is pouring out light and heat energy at a tremendous rate. The earth gets only a very small fraction, about one two-billionth, of the total amount radiated. From biological and geological evidence, we find that the sun has been pouring out this energy in about the same way for several billion years. How can we account for this enormous evolution of energy in the form of heat? Where does the energy go which does not strike the earth? Men in all ages have speculated on these questions, but as yet they have not been answered to our satisfaction. We may immediately dismiss such ideas as that of a furnace burning coal. Were the sun made of pure coal and giving out heat at its present rate, it would burn up in about 1000 years.

One of the earliest guesses was that meteors (shooting stars) were continually falling into the sun and that the heat developed by the collisions kept up the temperature. The difficulty with this explanation is that the sun would continually increase in size and this would in time change the pull of gravity and upset the solar system. Apparently, nothing of this kind is happening.

Helmholtz (1821–1894), a German physicist, advanced the theory that the sun was contracting, and as it became smaller the temperature was increasing. Though a very good theory, there are serious difficulties with it, therefore it has been practically abandoned. Such a contraction could not have supplied sufficient energy for several billion years.

Another idea which has been suggested is that radium in the sun supplies the heat. The element radium, used in the treatment of cancer (Chapter 14) has the property of continually giving out heat to the surroundings. If radium is placed in a closed container, the temperature of the container rises, and remains

higher than the surroundings. If the sun were to contain great quantities of radium, for which we have no certain evidence, a source of heat would be possible, but the life of radium is too short, only a few thousand years. This heat source will not solve the problem.

The most recent theory has been brought forward as the result of the work of *Einstein* (Fig. 15), in his theory of relativity.

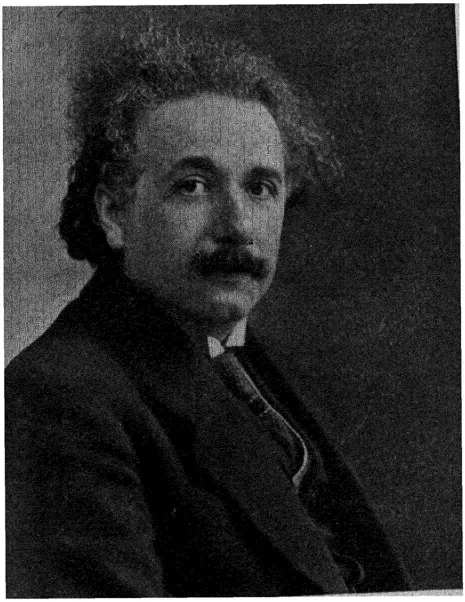

FIG. 15.—Albert Einstein (1879-) stated the principle of relativity; made many contributions to modern atomic theories; a great mathematical physicist. Director of the Institute for Advanced Study at Princeton University. (*Science Service.*)

Previous to this theory, scientists believed that there were two things making up the universe; matter and energy. These were believed to be separate entities which could be neither created nor destroyed. Einstein predicted that matter under certain conditions could be transformed into energy. From the theory we may calculate that the annihilation of one gram of material (for example, a few grains of sugar) is equivalent to the

burning of several thousand tons of coal. In 150 billion years, the sun's mass would need to decrease by only one one-hundredth of its original amount in providing the energy which it has emitted.

Since the speed of atoms depends upon the temperature, at 70,000,000 degrees Centigrade (the probable temperature of the core of the sun) the atoms and electrons may be moving so fast that actual annihilation takes place when they collide. The atom has actually changed into energy, and the mass has disappeared. Such an idea is outside our experience and consequently difficult to appreciate. This theory assumes that the mass of the sun is decreasing at the rate of 4,000,000 tons per second. But even at this rate, it can be shown that most of the mass remains. This does predict an eventual disappearance of the sun at some future time, which would mean an end of the solar system.

The word annihilation is difficult to explain. When a fragment of paper burns, some heat is emitted, but the smoke, gases, and ash remain. In annihilation, no gas or ash would remain, energy being the only residue. Such a phenomenon does not occur on the earth as far as we know.

As a result of the theory of relativity we have the equation $E = MC^2$, where E is the energy in ergs, M is the mass in grams and C is the velocity of light in centimeters per second. Thus the energy per gram is 9×10^{20} ergs, which is equivalent to 2×10^{10} kilogram calories. 2000 kilogram calories is the normal body requirement derived from food. At this rate the annihilation of one gram of sugar would supply body heat for 10,000 years!

The recent work in nuclear disintegration has given another clue to the perplexing problem of the sun's heat. If a lithium atom is struck by a hydrogen nucleus (proton), two helium nuclei are produced, and some mass is lost in the process. This lost mass may be the source of the sun's energy. Such an explanation seems to indicate that hydrogen builds heavier atoms and in the process heat is evolved. Inasmuch as hydrogen is plentiful in the sun and in the stars, this theory has a very satisfactory basis. We may in the near future acquire a satisfactory understanding of the sun's heat. The reader should refer to Chapter 14 for a more comprehensive account of this theory.

$$Li_3^{7.018} + H_1^{1.008} \rightarrow He_2^{4.0039} + He_2^{4.0039} + \text{energy}$$

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PROBLEMS

1. Describe the various layers of the sun.
2. Describe the principles of reflectors and refractors.
3. What evidence is there for a rotation of the sun?
4. What is a star? A Fraunhofer line?
5. Describe sun-spots.
6. Give three explanations for the cause of the sun's heat.
7. Describe a spectroscope.
8. Why are some elements not found on the sun?
9. If the sun were to become cooler what effect would it have on the earth?
10. Why is the Einstein theory of the cause of the sun's heat the most curious, yet the most reasonable?

TOPICS

Sun-spots.	Doppler Effect.	The new 200 inch Telescope.
Telescopes.	Einstein.	Newton.

EXPERIMENTS

Using a spectroscope of the type shown (Fig. 13), study the line spectra of sodium, lithium, and hydrogen. To produce the yellow lines of sodium, use a piece of glass rod in a bunsen flame, or a roll of asbestos soaked in salt water.

For hydrogen use a hydrogen discharge tube.

Use lithium chloride in a flame to produce the red line of lithium.

Using sunlight or an electric light bulb, examine the continuous spectrum.

If a direct vision spectroscope is available, view the Fraunhofer lines in the sun's spectrum.

3

THE STARS

"These great orbs thus radically bright
Primitive founts and origins of light."
Prior

THE STARRY heavens have been a source of amazing wonder to people of all times. Shepherds and astrologers, peasants and princes, alike felt a sense of awe when gazing at the night-carpeted sky. Ancient peoples imagined that shapes of various animals were set among the stars (Maps I–IV). There are dogs (Canis Major and Minor), bears (Ursa Major and Minor), a lion (Leo), a bull (Taurus), a dragon (Draco), and various birds, but no elephants, tigers, or camels. Probably Babylonia and Persia furnished the forms of many groups of stars. Later, other constellations were named from the myths of Greece and Rome. We have Cepheus, Perseus, Andromeda, Pegasus, and Cassiopeia. Other constellations are Auriga, the charioteer; Bootes, the herdsman; and Orion, the hunter.

The entire myth of Andromeda is recorded in the heavens. King Cepheus and Queen Cassiopeia had a beautiful daughter Andromeda, who was condemned by the gods to be sacrificed to the sea monster, Cetus. The hero, Perseus, mounted on the winged horse Pegasus rescued the maiden. The entire group is found in the northern constellations.

Another interesting story concerns Orion, the mighty hunter, who had the misfortune to be loved by Diana. The sky shows Orion accompanied by his dogs, Canis Major and Canis Minor, hunting the bull, Taurus. On the shoulders of Orion we find the great star Betelgeuse, and at his feet the star, Rigel. In Canis Major is Sirius, and in Canis Minor is Procyon. This group form winter constellations. The teacher of young children will do well to use some of these myths as stories to arouse interest in the stars and in their positions.

The names of some stars in the constellations come from Arabia, such as Betelgeuse, Rigel, Alcor, Mizar, Deneb, Aldebaran. Others are of Roman origin; Capella, Vega, Spica, Sirius. Stars having names are those which are very bright (first

STAR TABLE

Name	*Constellation*	*Apparent Magnitude*	*Type*	*Distance Light Years*	*Diameter Sun = 1*	*Density Water = 1*
Sirius	Canis Major	−1 6	A	8 8	1.8	4
Canopus	Argus	− 86	F	540		
α Centauri	Centaurus	+ .05	G	4	1.1	1 0
Vega	Lyra	+ .14	A	27	3	1
Arcturus	Bootis	+ 25	K	38	30	3×10^{-4}
Betelgeuse	Orion	1 0	M	270	400	5×10^{-7}
Aldebaran	Taurus	1 05	K	57	38	5×10^{-5}
Antares	Scorpius	1 20	M	160	450	4×10^{-7}
Deneb	Cygnus	1 33	A	650	.7	1 3

or second magnitude). The unaided eye can see under the best conditions only about 2000 stars. However, because of its light gathering power, one could photograph by means of the 100 inch telescope several billion stars. (Fig. 16.) Because of the enormous number of the stars, thousands are known only by a number or a Greek letter and millions have not even a number. Some of the bright stars are described in the table.

Each of these stars is a sun like our own. Each radiates light and heat energy into the surrounding space. With the exception of our sun, all the stars are very remote. The nearest star, Proxima, in the constellation Centaurus, is about 4 *light-years* (24 million million miles) distant. (This star is not visible in northern United States.) Many of the stars are far larger than the sun, while other are smaller. Some are very hot, while others are comparatively cool. Blue stars such as Sirius (the brightest star in the sky) in the constellation Canis Major, have surface tem-

peratures of about 18,000°F., while red stars, such as Aldebaran in the constellation Taurus, are rather cool, 5000°F. Moreover, it is quite certain that there are dark bodies in the sky which were once luminous, but have now cooled. The Coal Sack in the southern sky is probably a mass of dark material that obstructs our view into outer space. All the stars clearly visible in our

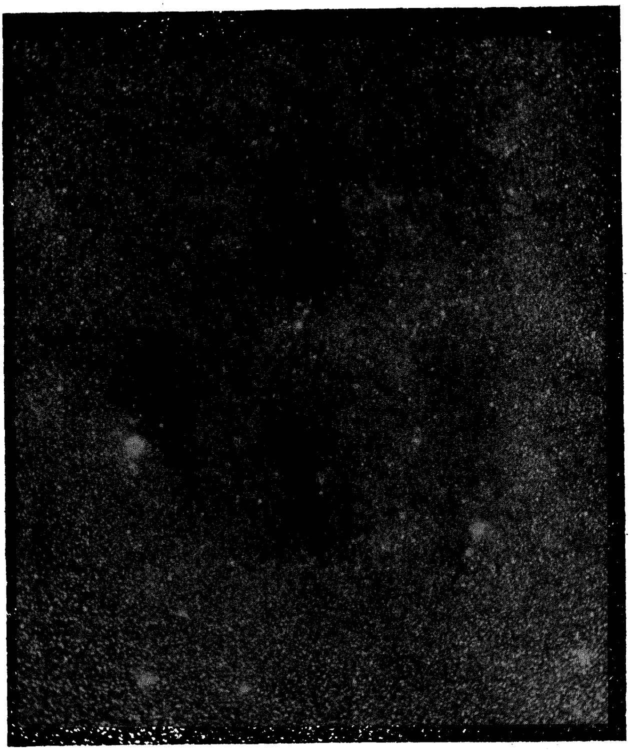


FIG. 16.—A star field. (*Yerkes Observatory.*)

telescopes, including some cloudy patches such as the Orion nebula (Fig. 17), and some star clusters (Fig. 18), constitute *our own galaxy.*

The galaxy is bounded by the "Milky Way," a band of misty light which really consists of an enormous number of distant stars. Our universe seems to have a shape somewhat like a flat biscuit. The rim of the biscuit is the Milky Way.

STAR SPECTRA. Although the sun and the planets have been studied for centuries, it is only within the last one hundred years that the stars have received special attention. In 1824, Fraunhofer was able to study the spectra of some of the bright stars. With the development of photography, a new era dawned in star study. In 1885, Pickering at Harvard set out to photograph star

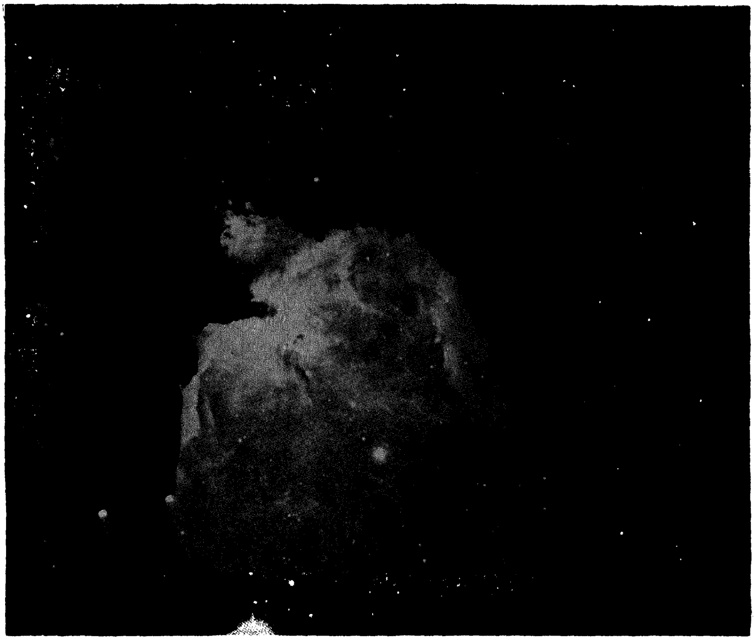


FIG. 17.—The Orion nebula. (*Mt. Wilson Observatory.*)

spectra. (Figure 19 shows various types of star spectra. Most of the lines are dark Fraunhofer lines. A few stars show bright line spectra.) After 40 years of work, there are recorded measurements of over 200,000 stars. A few of these stars have the curious property of flaring up to intense brightness and then slowly fading. These stars are called *novae*. No explanation for such behavior has been found. Two famous *novae* are one in Aquila, which was very bright in 1918, and one in Hercules, which flared up in 1934.

The stars show great differences in the type of Fraunhofer lines produced by their atmospheres, and for convenience they have been divided into classes. We shall mention only a few of these. Class *A* stars, of which a good example is Sirius in Canis Major, show strong hydrogen lines and lines of some metals. They are fairly hot, having a surface temperature of about

FIG. 18.—A globular star cluster in Hercules. (*Yerkes Observatory.*)

10,000°C. (18,000°F.). Class *G* stars, of which the sun, and Capella in Auriga are examples, show evidences of many metals such as sodium and calcium. The surface temperature is about 6000°C. Class *M* stars have a surface temperature of about 3000°C. and are distinctly reddish. Their atmospheres contain such metals as titanium. Betelgeuse is an example. There are a few stars which seem to have temperatures as high as 30,000°C. These are called class *O*. Star temperatures are measured by the thermocouple

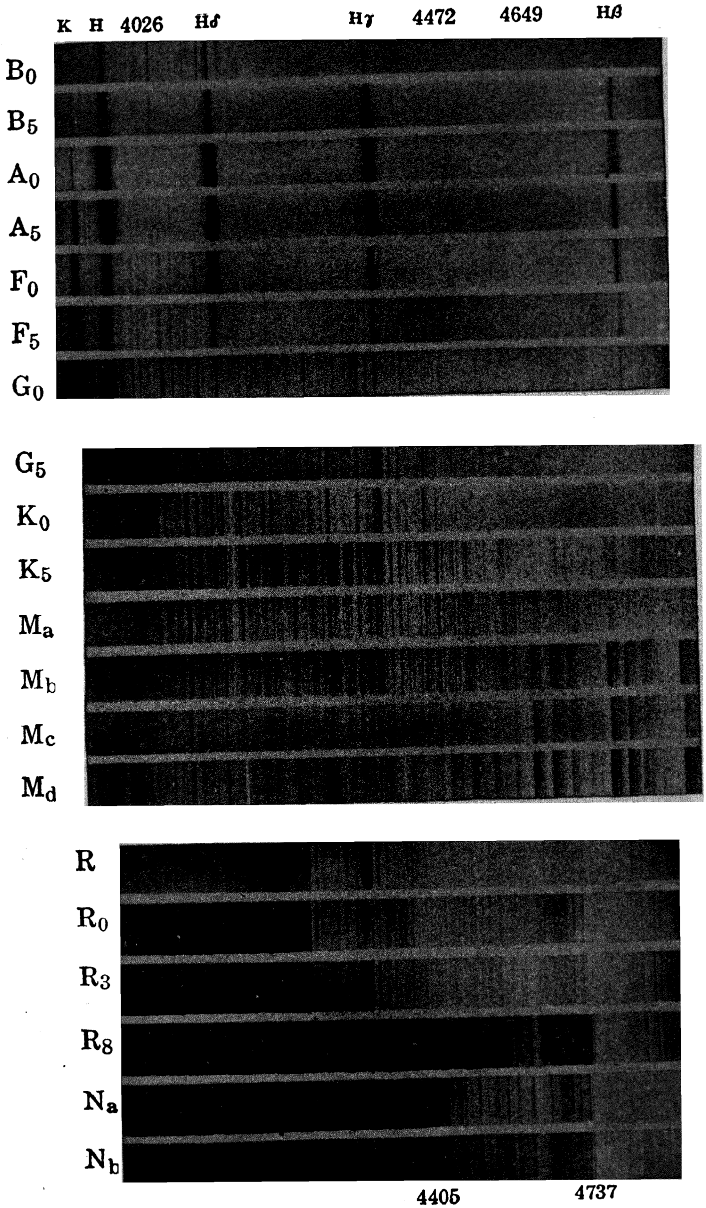
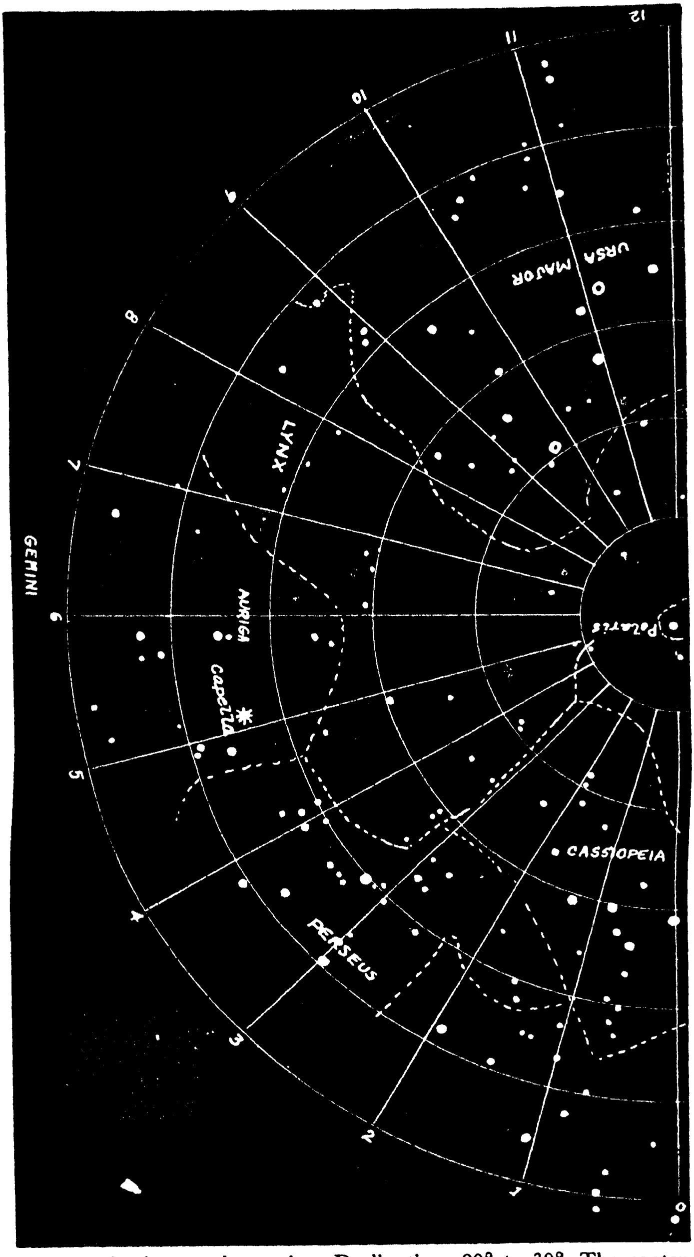
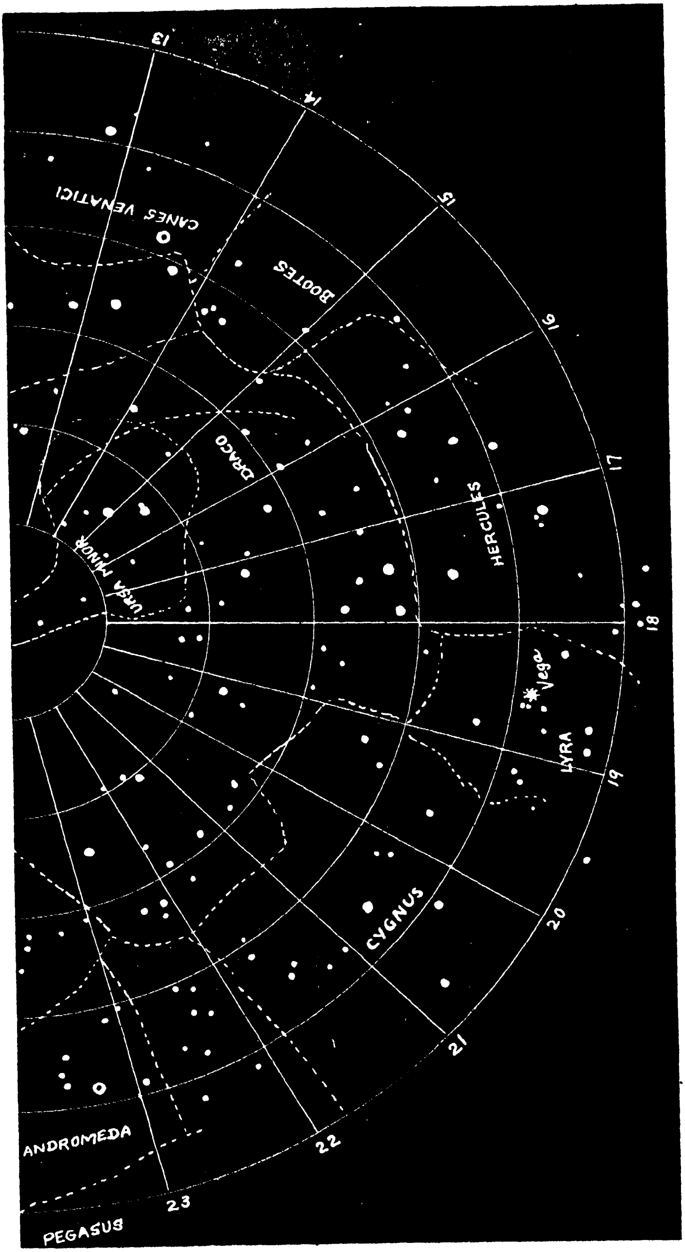


FIG. 19.—Star spectra of different types. Photographed at the Detroit Observatory. (*From Duncan's "Astronomy." By permission Harper and Bros.*)



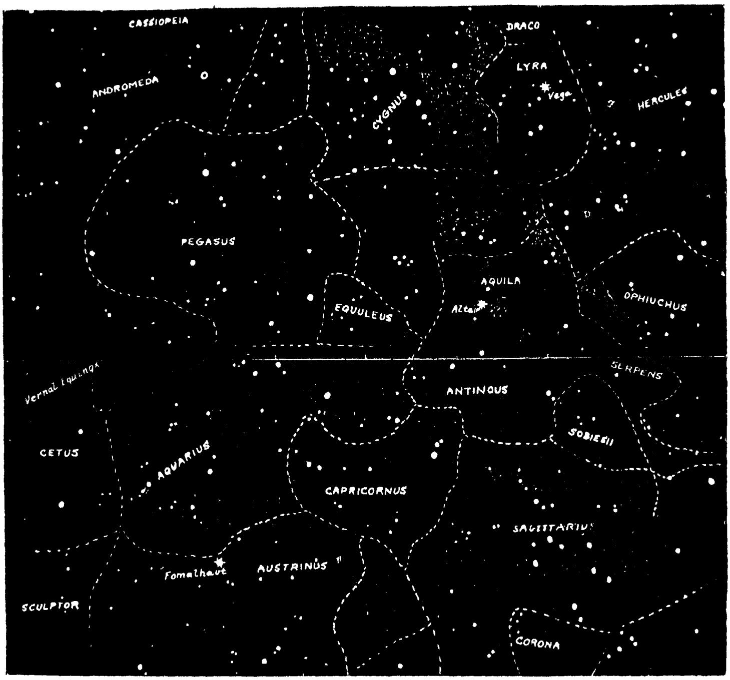
MAP I.—The north circumpolar region. Declinations 90° to 30°. The center of



the map is 90°. * First magnitude. O Nebulae. (*In using the map the observer faces north.*)

(see p. 240). It is interesting that there are no evidences for unknown elements in any star. This is a great aid in explanations of the origin of stars.

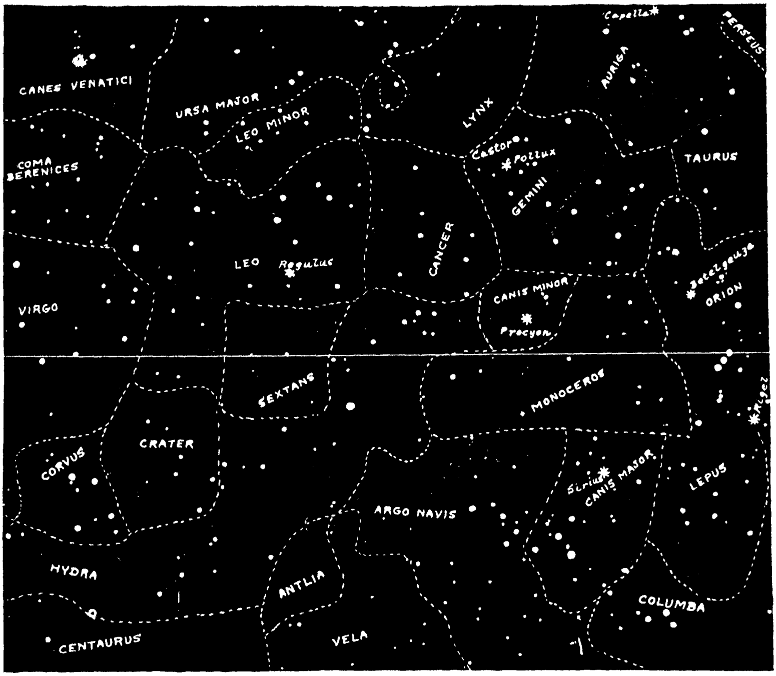
LOCATION OF STARS. In order to locate a star in the sky, it is necessary to have some reference lines. To do this, we may imagine ourselves at the center of a great hollow ball which is



MAP II.—Constellations visible in the United States, October 1, 8 P.M., September 15, 9 P.M. In using this map the observer should face the south, holding the map in a position such that Cygnus is directly over head. The line passing through the center of the map is the celestial equator. This map shows the position of the vernal equinox. Note the Milky Way.

studded with stars. The axis of the earth points toward a star in this ball which is called Polaris (the north pole star). A circle drawn around this ball over our equator is the celestial equator. Just as latitude on the earth is measured from the equator to the pole, so *declination* is the term used to measure distance from the celestial equator to the pole star. Instead of longitude we use the

term *right ascension.* Right ascension is measured eastward from the point in the sky where the sun meets the equator at the beginning of spring (*vernal equinox*). (The vernal equinox is a point on the celestial equator just south of the constellation Pegasus.) In this system, Vega in Lyra is located as follows: right ascension 18 hours 30 minutes; declination 38°. Because of

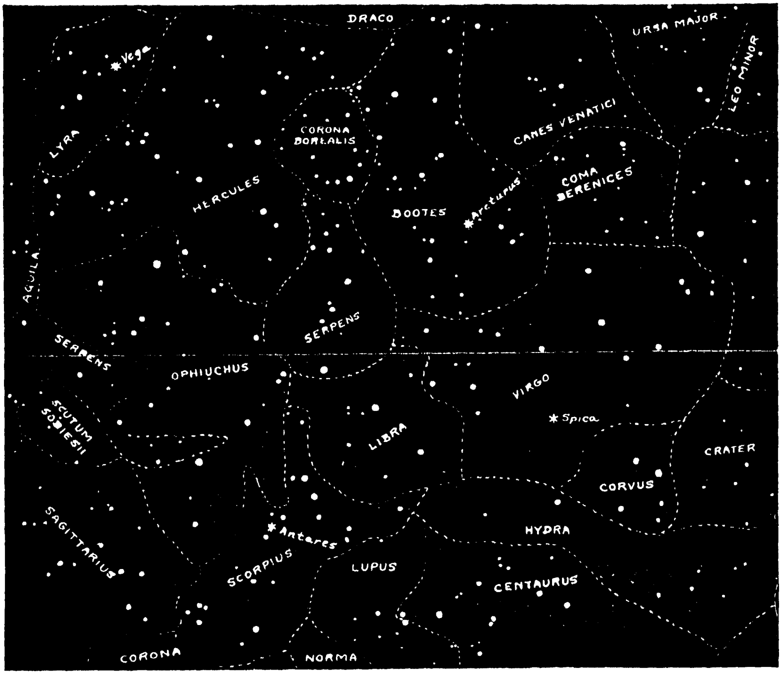


MAP III.—Looking south April 1, 8 P.M.; March 1, 10 P.M. In this part of the year Capella will be nearly overhead. In the sky will be found, Orion, Leo, and Canis Major.

the great number of the stars, it is difficult to place the entire sky on one map so that the sky is usually divided into sections. In plotting the northern sky it is best to use polar coordinate paper.

Map I represents the section of the sky known as the north circumpolar group. The center of the map marks the position of the star *Polaris.* The circles indicate *declination.* The radial lines

are *right ascension* lines.* For example, the star Alpha Auriga (Capella) has a declination of 47° and a right ascension of 5 hours and 10 minutes. (These numbers are only approximate, being read directly from the map.) Maps I–IV portray the brighter stars visible in the United States at various times of the year.



MAP IV.—Looking south June 1, 10 P.M., July 1, 8 P.M. This part of the sky contains Vega, Arcturus and Spica.

STAR DISTANCES

Star distances are so enormous that it is inconvenient to indicate these distances in miles. Instead, the term light-year is used in popular language. This term means the number of miles which light travels in a year. Arcturus, in Bootes, is said to be about 40 light-years distant. This expression means that the light which

* The declination circles are spaced at 10° intervals. Each right ascension line represents one hour. In Map I, the circles extend from 90° to 30° and the lines extend from 1 to 24.

reaches the earth tonight from Arcturus, left the star 40 years ago. Perhaps it is more startling to make the equivalent statement: If the star were to become dark today we would still receive light for 40 years. Light travels in free space at a rate of about 186,000 miles per second. (This means that the light comes from the moon in about one second, from the sun in 8 minutes, and from distant planets in intervals of hours.) Since there are about 31,000,000 seconds in a year, this means that a light-year is

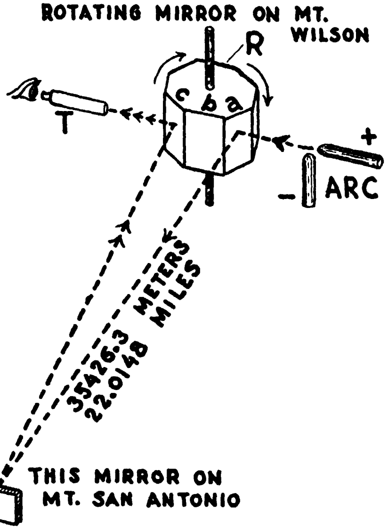


FIG. 20.—Michelson's method of measuring the velocity of light. (*Foley.*)

about 6 million million miles. An aviator would require 600,000 years to reach Sirius.

SPEED OF LIGHT. The speed of light has been determined by many observers, the latest being Michelson of the University of Chicago. (Dr. Michelson, before his death in 1932, had measured the diameters of several stars by the interference method.*) By using a rotating mirror on one mountain and reflecting the light from a mirror on another mountain 20 miles distant, he was able to make a very accurate calculation of the speed of light. Figure 20 illustrates the method. Light from the arc is reflected from the face *a* of the rotating mirror. Upon reflection from the mirror *M*

* Consult any standard text on astronomy.

the light returns and is viewed by the eye as it is reflected from *c*. Since the distance was accurately known, Michelson only needed to determine the speed of rotation of the spinning mirror to calculate the speed of light through the atmosphere.

It is of interest to remark that the light which left Arcturus during the time of the Columbian exposition in 1893, was used to turn on the lights at the Chicago Century of Progress exposition in 1933, 40 years later. This was made possible by focusing a telescope on Arcturus and placing a photocell at the eyepiece. The electrical current produced in the photocell operated the light switch which turned on the lights at the exposition grounds.

STAR DISTANCES. It is beyond the scope of this text to explain all the methods by which enormous star distances are measured.

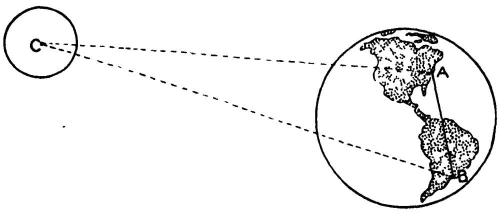


FIG. 21. —The diagram illustrates how the astronomer measures the distance to the moon and sun. (*Bowden*.)

Such measurements are very difficult, and only in the case of the nearest stars can the distances be measured directly. For such objects as the planets and the sun, the astronomer makes use of the methods of the surveyor. If the position of the object among the stars is observed by astronomers at the two observatories A and B (Fig. 21), the angle between these two positions can be determined, and since the distance *AB* is known, the distance *AC* can be easily calculated. For more distant objects the diameter of the earth's orbit is used as a base line (Fig. 22).

One of the recent methods which is of great importance is the *Variable Star* method. There are stars in all parts of the sky which are brighter on some nights than on others. Some of these stars, the *Cepheid Variables* (so-called because one of the stars is in the constellation Cepheus) flare up at regular intervals in the same manner that a fire brightens when fuel is added at regular intervals. *Moreover, the brightest of the type change their brightness most*

slowly. It was discovered that all stars of this type follow the brightness-time rule no matter how distant they are. In consequence, it is possible to determine the true brightness of each star and from this the distance can be found. Miss Leavitt of the Harvard Observatory made this discovery.

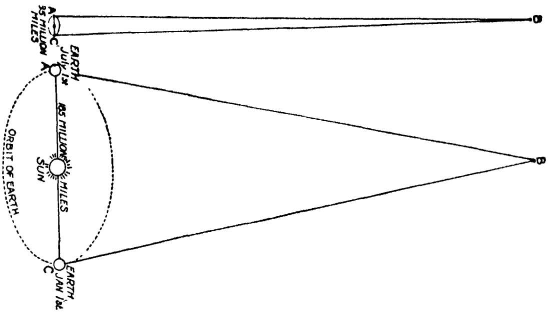


FIG. 22.—The diagram shows how star distances are measured. The line AC is the diameter of the earth's orbit. This line is the base line of the triangle ABC. B represents the star whose distance is to be determined. (*Bowden.*)

The interested reader should consult a reference text for a more complete explanation.

NEBULAE

Beyond the stars of our galaxy, which has for its boundary the Milky Way, there seem to be millions of other galaxies which are called nebulae (Fig. 23). The whole of the heavens seems to resemble a great ocean of space in which are scattered island universes. Some of the distant nebulae are several million light-years away. The Andromeda nebula is 900,000 light-years distant. Such distances are beyond comprehension. These nebulae seem to consist of stars and of great masses of glowing gas. Some seem to be rotating in enormous spiral forms like pinwheels (Fig. 24). It is hoped that the new 200 inch reflector will be of great service in the study of these other universes.

THE EVOLUTION OF THE UNIVERSE

At the outset it must be emphasized that any definite information concerning the formation of our present universe is lacking.

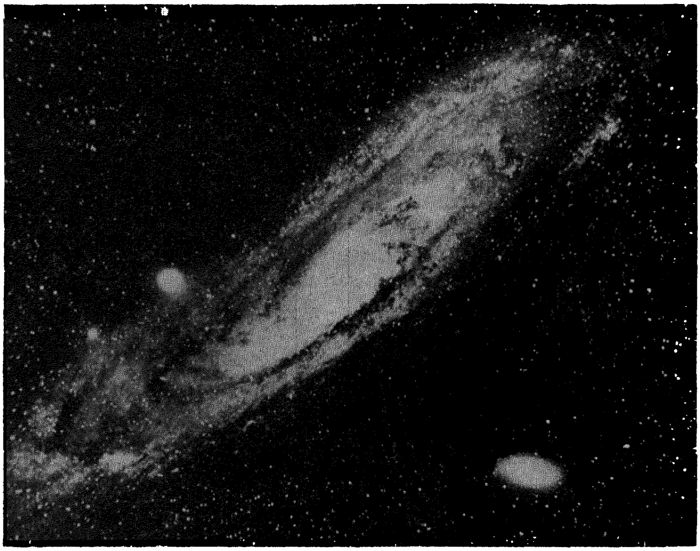


FIG. 23.—The nebula in Andromeda. (*A reprint of Yerkes Observatory negative N 101. By permission of the University of Chicago Press.*)

FIG. 24.—Spiral nebula (M81). (*Mt. Wilson Observatory.*)

We can only speculate, having as our basis the very fragmentary information gained from the heavens by powerful telescopes.

For a long time men have conjectured that the universe was originally filled with a gas without form (chaos). Perhaps this gas was composed of electrons? As time went on, this gas tended to coagulate, forming separate bodies. These enormous bodies we call *nebulae*. In these nebulae the process of the formation of the stars, which coagulated out of the formless gas, went on during countless years. By studying the nebulae it may be possible to form some better ideas of star evolution and to determine the size of the stellar universe.

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TOPICS

Nebulae.
Novae.
Variable Stars.
Star Distances.
Star Diameters.
Origin of the Universe.
Star Types.

VISUAL AID

EXPLORING THE UNIVERSE—Univ. of Chicago Film.

PROBLEMS

1. Describe the appearance of a nebula.
2. What is a star? a constellation?
3. What is a Cepheid Variable?
4. How can we measure the distance to a planet?
5. What is meant by a *G* type star?
6. How many miles in 10 light-years?
7. What is right ascension? declination?

8. How was the speed of light measured by Michelson?
9. For what is Arcturus famous?
10. For what is Miss Leavitt noted?

EXPERIMENTS

1. Plot the various constellations in the north circumpolar group (Map I). Use polar coordinate paper. This paper consists of concentric circles and radial lines. The circles are used for declination and the lines for right ascension. (Such paper is supplied by the Eastern Science Supply Co., Boston, Mass.)

2. Using a test star chart furnished by the Eastern Science Supply Co., write in the names of the principal stars from Map I of the text.

3. If desired, special sheets can be secured for the equatorial group, making it possible to plot the entire sky.

4. Choose the maps which correspond to the season of the year, and learn to identify some of the important constellations.

(Charts 1 and 2, pages 458–459 will be found useful in plotting constellations.)

4
THE MOON AND ECLIPSES

"O Lady Moon, Your horns point toward the east,
Shine, shine, be increased, be increased.
O Lady Moon, Your horns point toward the west,
Wane, wane, be at rest. Lady Moon, Lady Moon."
Rossetti

NEXT TO the sun, the best known object in the heavens is the moon. This bright object, varying in shape from a crescent to a complete disc of spotted appearance, is a frequent night visitor. Unfortunately, it is in the night sky for only part of the month, and is seldom at full brightness, so that its light is not dependable. As in the case of the sun, man has from earliest times endowed the moon with supernatural powers. The light of the moon was believed capable of producing moon-madness, and our word *lunatic* comes from the term lunar-madness. Even today, many farmers insist that unless they plant potatoes and cucumbers in the dark of the moon, the crop will be poor. A ring around the moon is believed to predict wet weather. There is a basis of truth in this last idea, since the ring is due to high humidity and for this reason rain may be imminent.

GENERAL DESCRIPTION OF THE MOON

The moon is the closest celestial object, the distance from the earth varying from 220,000 to 250,000 miles. Its diameter is 2160 miles and it is about 1/64 the size of the earth. It is a dead body, having, as far as can be observed, no atmosphere and no internal heat. This lack of atmosphere can be determined by viewing the edge of the moon (Fig. 25). The rim is very sharp, whereas it would be hazy if gases were around the body. When a star moves across the edge of the moon it is suddenly eclipsed. If an atmosphere were present the disappearance would be gradual. At the time of a total eclipse of the sun the light shines between the

jagged mountains of the moon, causing the "Baily beads." These phenomena indicate that no atmosphere exists on the moon. The spectroscope indicates that no water exists on the moon.

Any possible atmosphere may have been lost because the pull of gravity on the moon was not sufficient to prevent the escape of the rapidly moving gases (see p. 145). The force of gravity on the

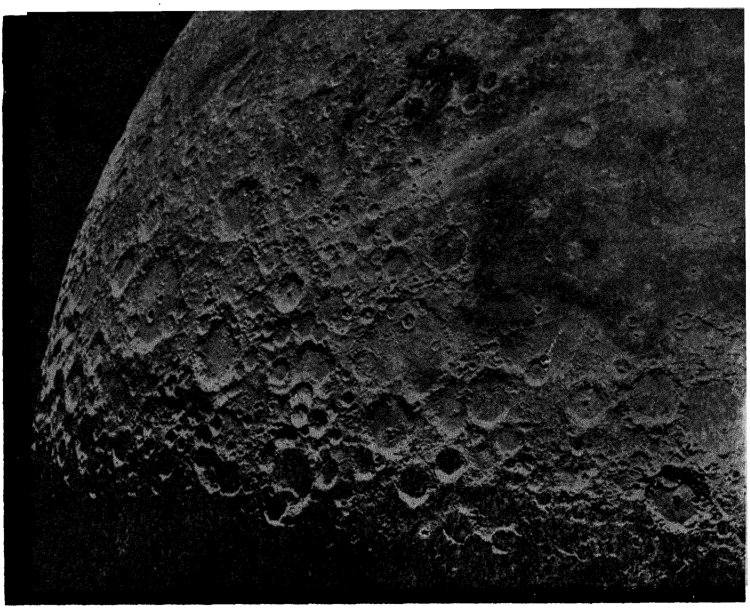


FIG. 25.—Craters on the moon. (*Mt. Wilson Observatory.*)

moon is much less than on the earth. It is believed that most of the hydrogen and helium on the earth have escaped into outer space, because the pull of gravity was not sufficient to retain these light gases. On the moon, it is possible that even the heavy gases such as oxygen and carbon dioxide have escaped, leaving no atmosphere.

TELESCOPIC APPEARANCE

As a contrast to the sun, the appearance of the moon in a telescope is very interesting. One finds mountain ranges, sharp

peaks, and deep craters. There are other areas called *seas*, because the early observers thought that they contained some liquid. Actually these seas are rock areas. Some of them have interesting names such as: the Sea of Tranquillity, the Sea of Nectar, the Sea of Dreams.

In contrast to the earth, where the peaks are rounded off by the action of weathering, the mountains on the moon consist of jagged peaks, which show no evidence of climatic action. There

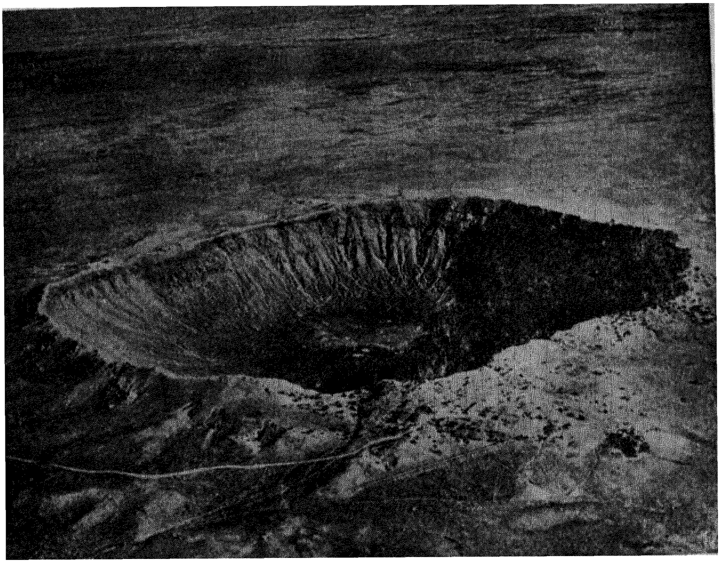


FIG. 26.—Meteor crater in Arizona. (*Courtesy Transcontinental and Western Air, Inc.*)

are several mountain chains, among which are the Apennines, the Alps, and the Caucasus mountains. The Apennines alone have several thousand jagged peaks. Were we able to make a trip to the moon, we would find walking very difficult. The rocks are probably like rough lava.

The crater-like depressions have been the subject of much study. There are about 100,000 on the side visible to us. One of the largest craters is named Theophilus. The floor of this crater is 64 miles wide and contains three mountain peaks. It resembles a cup with cones at the bottom. Probably the best explanation of

these holes, some as large as 100 miles in diameter and several miles deep, is that they are the result of volcanic action. However, no direct evidence of such action has ever been observed. Another explanation is based on the fact that the moon is doubtless bombarded by meteors (see p. 62) and these holes may be the result of the collisions. Several examples of such action exist on the earth. In northern Arizona there is a crater called Meteor Crater. This hole is about one mile in diameter. (Fig. 26.) Great masses of meteoric material have been found around it. It is believed to have been caused by the fall of a great meteorite in prehistoric times. On July 30, 1908, a catastrophe happened in the Province of Yenisei in Siberia. Although no one saw the event, many trees were mowed down, and thousands of reindeer were killed. Because of the inaccessibility of the region, only within the last few years have scientists penetrated into the locality. It seems fairly certain that a great meteorite fell in the region, but up to the present it has not been found.

Unfortunately for the meteor theory as applied to the moon, the craters are not distributed uniformly over the surface of the moon, and it is difficult to understand how meteor showers could be concentrated only in certain parts of the surface.

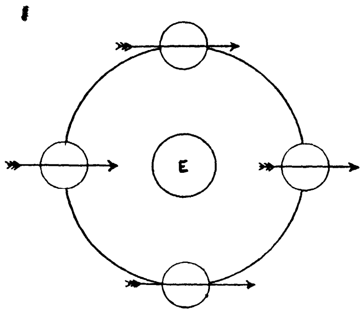
Temperature

The temperature of the moon is subject to great changes. On the earth, the temperature is made rather uniform because the oceans and the atmosphere retain the heat and prevent rapid changes of temperature at night. In the daytime the atmosphere acts as a shield to prevent too high a temperature. But, since a lunar day is 29 earth days in length, one side of the moon is exposed for a long time to the sun and, because of the lack of atmosphere, the daytime temperature is above the boiling point of water. At night the temperature falls to a value lower than the lowest temperatures on the earth.

Phases

The most remarkable things that one observes in connection with the moon are the *phases*, or changes in shape during the lunar

month. The moon presents *all faces* to the sun during the month, so that the sun always illuminates some half of the moon's surface; but, because of the fact that the moon revolves about the



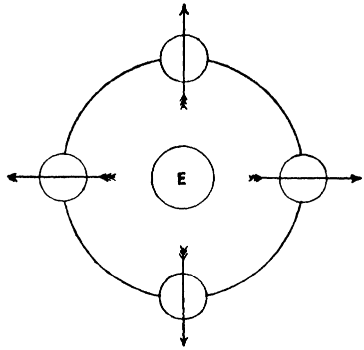


FIG. 27(a). FIG. 27(b).

Fig. 27(a) represents revolution without rotation.

Fig. 27(b) represents revolution with rotation. In this case an observer on the earth sees only one face of the moon.

earth in such a way that it always presents the same face to the earth, we do not often see the entire lighted face. The moon rotates once during the month. (Figure 27(a) represents revolution without rotation. Figure 27(b) represents rotation with revolution.)

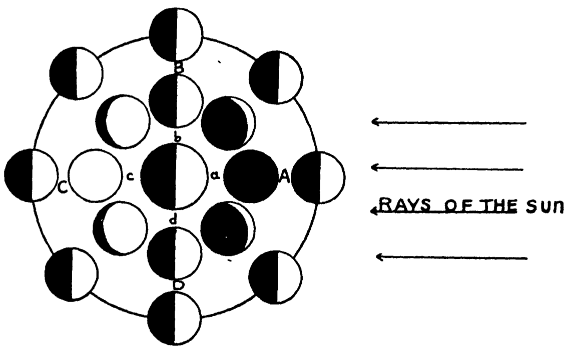


FIG. 28.—Phases of the moon.

In the drawing, (Fig. 28) the outside circles represent the actual lighted surfaces, while the inside circles indicate the corresponding phases as seen from the earth.

When the moon is in position *A* (conjunction) and we are at position *a* on the earth, the moon is in the sky in the daytime but we do not see it. This is *new moon* or *dark of the moon.* When the moon is at position *B* (quadrature) and we are at *b* we see one-half of the face (*first quarter*). During this phase the moon is overhead at sunset. When the moon is in position *C* (opposition) and is above or below the plane of the earth's orbit, we have full moon at position *c* on the earth. Finally, if the moon is at position *D* and we are at *d*, the moon is in the sky at sunrise.

Between these positions we have the crescent moons beginning with new moon and increasing in size (*waxing*) until full moon is reached. The moon then *wanes* until new moon is reached.

An easy method for the demonstration of the peculiar rotation and revolution of the moon is to mark a spot on a ball which will represent the moon and to carry this ball around another ball representing the earth, always keeping the spotted side facing the earth-ball. If an electric lamp is used to represent the sun, the phases can be seen in a darkened room.

ECLIPSES

Should the moon when at position *C* be in the plane of the orbit, so that the sun, moon, and earth are in line, the earth would cast a shadow over the moon and we would have a lunar eclipse. Obviously, this can occur only at night. Since the moon does not often get into the plane of the orbit, both solar and lunar eclipses are infrequent at any one part of the earth. A lunar eclipse lasts much longer than a solar one, because the earth casts a much larger shadow on the moon than the moon casts on the earth. Although eclipses of the moon are interesting, they are of little scientific importance. (Fig. 29.)

In order for a solar eclipse to occur, not only must the moon be in *conjunction* (*A*), but it must also cross the plane of the earth's orbit at the same time. Because the moon is very small compared to the sun, the exact conditions are not often fulfilled. If the moon is at its greatest distance from the earth, the moon's disc is not large enough to completely cover the sun's photosphere. In this case we have a ring or *annular* eclipse. These eclipses are of little interest to the astronomer. There may be as few as two solar

eclipses in a year, or as many as five. Since most of these are either partial or annular and since in the event of a total eclipse, the path of totality is very narrow, about 100 miles wide, a total eclipse at any one location occurs very infrequently. As an illustration, an eclipse occurred in eastern United States in 1932. The next eclipse in that section will not occur until 1963.

A solar eclipse is a magnificent spectacle. As the moon begins to touch the face of the sun, there is at first no noticeable change. After about one-half of the sun's disc has been covered, objects begin to cast strange shadows. During the few seconds which precede totality, the sky has a strange appearance somewhat like a smoky atmosphere. At the instant before totality, the

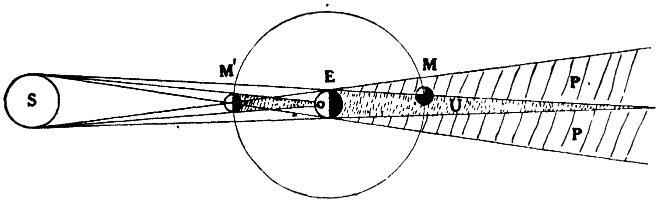


FIG. 29.—Drawing of solar and lunar eclipses. Moon at M′ produces a solar eclipse; at M it forms a lunar eclipse (*Weld and Palmer.*)

moon's shadow comes rushing across the western horizon like a storm; the sky is dark violet in color; the observer has the sensation of approaching disaster. As the observer gazes at the sun, he may see brilliant beads of light as the sun shines between the mountains of the moon. During the period of totality the corona flashes out brilliantly; the bright stars appear; Mercury is visible. The appearance is that of a peculiar twilight. It is not surprising that early peoples were terrified by the spectacle. Probably no spectacle of nature is more awe inspiring. Ancient peoples believed that the eclipse was sent by the gods as a punishment. The Scandanavians made a great noise to chase away the animals who were devouring the sun.

The solar eclipse is of vital importance to the astronomer, because only at such a time can he study the corona, check some of the principles of the theory of relativity, and search for new planets close to the sun. Unfortunately, eclipses are not often

conveniently located for observation. On June 8, 1937, an eclipse occurred in a region of the Pacific ocean where there were only two small islands. The importance of this eclipse was its length, about 5 minutes.

Earth Shine

One of the curious phenomena that we observe in connection with a narrow crescent moon is called the "old moon in the new

Fig. 30.—Earth shine. (*A reprint of Yerkes Observatory negative M45. By permission of the University of Chicago Press.*)

moon's arms." As one observes carefully the lighted crescent, he may see faintly the rest of the face. The faint illumination on the dark part of the face is due to light reflected from the lighted side of the earth to the moon and reflected back from the moon to the dark part of the earth. This is "earth shine" (Fig. 30).

TIDES

The only effect that the moon has on the earth is the gravitational one, causing tides. The sun also causes tides, but these are

less important, because of the great distance of the sun from the earth. Every day there occur two high tides along the sea coast, coming at intervals of about 12½ hours. Between these high tides there are periods of low tides. The earth rotates on its axis once every 24 hours. The moon is moving eastward around the earth, completing the circuit in about 29 days. Because of these two motions, the moon crosses the *meridian* (a line passing from north to south through a point directly overhead) every 24 hours and 51 minutes. There are two high tides in this interval as will be explained later, and, as a result, the time of high tide changes from day to day and must be ascertained from tide tables. Tide

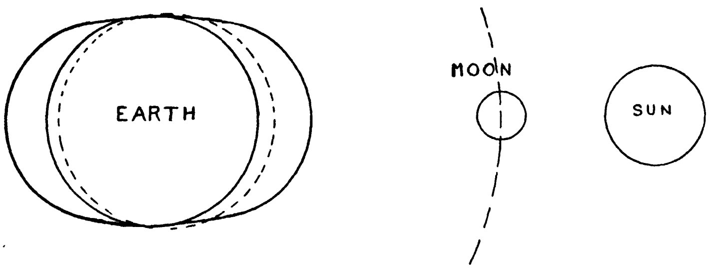


FIG. 31.—A figure illustrating the cause of tides. The combined forces of the sun and moon in this position cause spring tides.

prediction at any point requires many records of previous tides. At the coast resorts, the times of high tides are announced each day for the benefit of bathers at the beaches. When the sun and moon are in *conjunction* (both on the same side of the earth), or in *opposition* on opposite sides of the earth, the tides are exceptionally high and are called *spring tides.* When the moon is in *quadrature* (half way between conjunction and opposition) we have the *neap tides.* These are minimum high tides. (Fig. 31.)

CAUSE OF TIDES. The law of gravitation teaches that between any two objects in the universe, there is an attraction which depends on the masses of the bodies and upon the square of the distance between them (see p. 221). The causes of this attraction are not well understood, but it is believed that the same action that operates in the case of bodies on the earth takes place between celestial bodies.

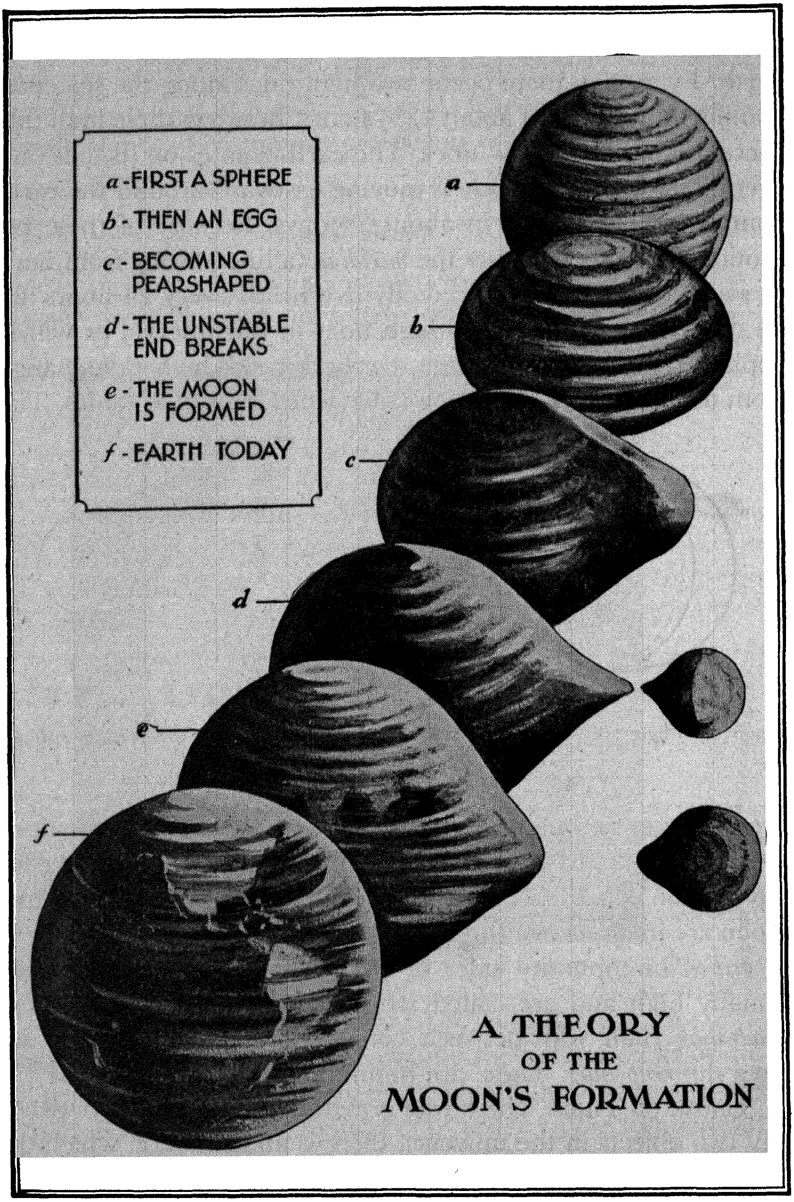


FIG. 32.—A theory of the formation of the moon. (*From Stetson's "Man and the Stars," after Jeans and Darwin, courtesy McGraw-Hill Book Co.*)

The moon, because of its gravitational pull upon the earth, attracts the water of the ocean directly below it more strongly than it attracts the ocean floor. It thus pulls the water away from the floor and produces a great wave. On the opposite side of the earth, the solid earth being nearer, is pulled away from the water, causing another wave. This results in a heaping of the water on opposite sides of the earth at the same time. As the earth rotates on its axis, the water follows the moon as two great waves in the oceans. Because of the speed of rotation of the earth, the water lags behind and high tides do not occur when the moon is overhead. If the surface of the earth were smooth and entirely covered by deep water, the tides would follow the moon in a simple manner, but, owing to the varying depth of the seas and the irregularities of the land masses, the water cannot keep pace with the moon. The height of a tide varies from two feet in mid-ocean to a maximum of 50 feet in the Bay of Fundy. The high tide in the Bay of Fundy has been studied with a view of producing electrical power from the rise and fall of the water. Preliminary construction has been recently started toward this end in Passamaquoddy Bay.

THE ORIGIN OF THE MOON

When a body is started into revolution about another and there is no force to slow it down, it will continue to revolve under the action of the force of gravitation. Thus the moon, having been started at some time, continues to revolve at a practically constant rate and will probably continue to do so for a long time to come. There is no certain explanation of the origin of the moon. One assumption is that the moon was separated from the earth in early geologic time. Figure 32 is a drawing which illustrates this theory. However, there are grave objections to such an explanation.

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PROBLEMS

1. Explain the cause of a total eclipse of the sun.
2. Explain the manner of the moon's rotation.
3. Describe the phases of the moon.
4. What is earth shine?
5. Why has the moon no atmosphere?
6. What is the cause of tides? Describe them.
7. Can a lunar eclipse be seen at noon? Explain.
8. What is the phase when sun, moon, and earth form a right angle?

VISUAL AID

THE MOON—University of Chicago Film.

TOPICS

Phases. Solar eclipses. Tides. Meteor Craters. Passamaquoddy.

EXPERIMENTS

1. Predict tides for your locality by use of an almanac.
2. Map the lunar craters. Use lantern slides or moon maps.
3. Using the Nautical Almanac, which can be secured at nominal cost from the Superintendent of Documents, find the time of moon-rise and moon-set for the first day of each month of the year. From this information predict the various phases on those days.
4. Make a drawing showing the various phases for each day of a month.

5
PLANETS AND OTHER BODIES OF THE SOLAR SYSTEM

"From the great deep before our world begins
Where all that was to be in all that was
Whirled for a million aeons through the vast
Waste dawn of multitudinous eddying light."
Tennyson

PLANETS

OF ALL the celestial bodies which have stirred the imagination of man, probably none are more stimulating than the nine planets, those bodies which wander about in the heavens. Six of these were known in very early times. The word *planet* means *wanderer*. This name arose from the fact that the planets seemingly wandered about, their motion being relative to the fixed stars. The casual observer will note that there are often in the sky bright objects which do not twinkle. These objects will be found in various positions, and at times will disappear entirely. On a certain night Mars may be found in the location of the constellation, Leo, and on another night the planet may be located in Cancer. Or during another part of the year, Mars will be in the sky in the morning. The *planets are bodies which shine by reflected sunlight* and, like the earth, they revolve about the sun in nearly circular orbits. They are named from the Roman gods.

Because of the revolution of the earth about the sun, the sun seems to move eastward among the stars in a path called the *ecliptic.** All the planets, as well as the moon, will be found close to this path. The ecliptic passes through the locations of twelve

* Within the last few years, planetaria have been constructed which simulate the motions of the heavenly bodies. One such planetarium is illustrated in Figure 196.

constellations, called constellations of the Zodiac. These constellations are Pisces, Aries, Taurus, Gemini, Cancer, Leo, Virgo, Libra, Scorpius, Sagittarius, Capricornus, and Aquarius (see p. 82).

Any almanac will give the signs of the zodiac as they apply to various parts of the body. For example, Aries was believed to rule the head, Leo the heart, and Gemini the arms.

The subject of Astrology was based on the different positions of the planets among the stars. Mars and Saturn were believed to have a sinister effect on human affairs. In ancient times events were based on the relations of planets to the stars. Mars ruled wars; Venus controlled love and beauty; the moon controlled disease; Saturn provided a cold, callous nature; Jupiter was beneficent. When a child was born, a horoscope was cast which would indicate the course of his life. If the grouping of the heavenly bodies was favorable, the child might lead a fruitful life, free from sorrow and disease. Even today many people avidly follow the prognostications of astrologers.

PLANET TABLE

Planet	*Mean Distance from Sun, Miles*	*Year*	*Number of Moons*	*Sidereal Day*
Mercury	35,950,000	88 days	none	88 days
Venus..........	67,170,000	225 days	none	uncertain
Earth	93,000,000	365¼ days	one	24 hours
Mars	141,500,000	687 days	two	24 hours, 37 min.
Asteroids........	Various small planets between Mars and Jupiter			
Jupiter..........	483,200,000	11.86 years	nine	10 hours
Saturn..........	885,900,000	29½ years	nine	10 hours, 30 min.
Uranus..........	1,782,000,000	84 years	four	10¾ hours
Neptune........	2,792,000,000	165 years	one	15 hours
Pluto...........	3,673,000,000	247 years	unknown	unknown

MERCURY (The Messenger of the Gods). This is a small planet very close to the sun. Consequently, it is difficult to see. It is visible at the time of a total eclipse, also at some seasons of the year, when it will be found as a star-like body low on the horizon at sunset or sunrise. It is believed to have no atmosphere; it probably is very hot; and is of little interest to the amateur astronomer. Its main interest to the scientifically minded student lies in the

fact that the theory of relativity offers an explanation of its perturbed (disturbed) path around the sun.

VENUS (Goddess of Love). The next planet in order of distance from the sun is Venus (Fig. 33) called both the morning and evening star. During parts of the year, Venus is "west" of the sun and is visible in the east before sunrise. (A planet is "west" of the sun if it rises before the sun.) But at other times it is "east" of the sun and is visible in the west in the early evening. For part of the year it is on the opposite side of the sun from the earth and is not visible. It also presents phases like the moon. It is the brightest object next to the moon in the night sky. In fact, it is so bright that it can often be seen at mid-day. This gives rise to the statement that "one can see *stars* in the daytime." (Actually, a powerful telescope will make a few of the brightest stars visible in daylight.) For various reasons it is often called the twin of the earth. It has about the same diameter (7700 miles) and nearly the same mass. Unfortunately, it is one of the most difficult planets to study. Astronomers have tried to penetrate the cloud layer that covers the surface, but as yet no observer has ever seen the face of the planet. This cloud layer is not fully understood. In 1932, Adams and Dunham, using infra-red photographic plates, found evidence for immense quantities of carbon dioxide around the planet. So far, no evidence for the presence of oxygen or water vapor has been found. Inasmuch as oxygen and water vapor are necessary for life on the earth, this may mean that life has never begun on Venus. On the other hand, life may be abundant under the great cloud layer.

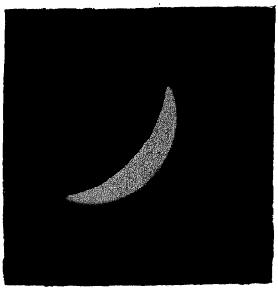

FIG. 33.—A crescent Venus. (*A reprint of Yerkes Observatory negative P2. By permission of the University of Chicago Press.*)

The planet has no moon that can be seen. The poles of Venus are probably as warm as our equatorial regions. No definite evidence for rotation has been found. The Doppler test (p. 11) fails to show any evidence for rotation.

EARTH. The next in order of the planets is the earth. This planet will be discussed in Chapter 6.

MARS. Beyond the earth is Mars, a reddish object (Fig. 34).

Although Venus is called the twin of the earth, Mars is very nearly the counterpart of our globe. It has two small moons (Deimos and Phobos), rotates on its axis in about 24 hours, has seasons like the earth, has an atmosphere which possibly contains some oxygen and water vapor, and shows polar caps of white material. Because of the small amount of water on the planet

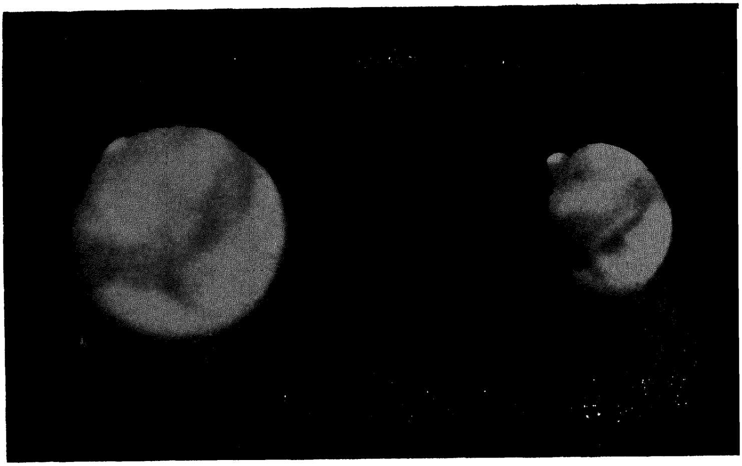

FIG. 34.—Telescopic views of Mars, showing polar caps. (*Mt. Wilson Observatory.*)

most astronomers believe that the polar caps are frost rather than ice caps.*

In 1877, Schiaparelli, an Italian astronomer, announced that he had seen long, straight, narrow (50 miles wide) streaks on the Martian surface (Fig. 35). Since that time many observers, including Lowell and Barnard, have studied the surface. Some agree that the markings exist, while others claim they are optical

* Both the telescope and the spectroscope are used in the study of the Martian surface and atmosphere. By the use of blue and red filters, the astronomers are able to form impressions concerning Mars. Most of the evidence is still uncertain but it seems that the atmosphere of Mars is very small in amount.

illusions. At present it seems certain that the markings do exist. Naturally, this has aroused much discussion as to whether Mars has life on its surface. It is probable that the planet has a little oxygen and some water and that the temperature (80°F. at the equator) is warm enough to support some form of life. It seems possible that life of some sort, perhaps vegetation, might exist on the planet, but probably not as we know plant life. Even on the earth, the forms of life are so varied that we can hardly make any speculations as to the forms of life on another planet. The theory of evolution teaches that the higher forms of life have developed

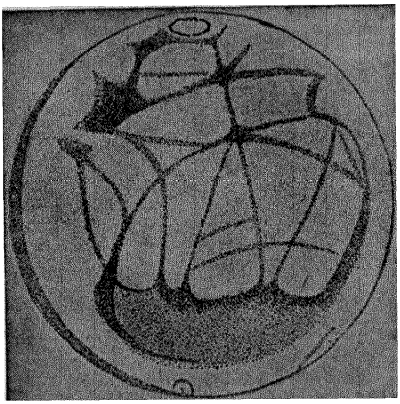

FIG. 35.—A drawing of the canals of Mars. (*After Schiaparelli.*)

from the lower types, and it may be that on Mars the process of evolution took very different paths, and that we would not recognize as familiar any forms of life there. Until we have penetrated the mystery of the origin of life, it is impossible to draw any conclusions regarding other worlds.

ASTEROIDS. In 1801, Piazzi, while searching for another planet between Mars and Jupiter, found a little planet which he named Ceres. Its diameter is less than 500 miles. Since that time more than 1300 of these small planets have been found. Many of them have received fanciful names. Some, such as Achilles, have been named after the Greeks. The gods are represented; various colleges are honored; feminine and masculine names are used; pet dogs are remembered. One of the most interesting of these small

planets, Eros, comes quite near the earth (about 16,000,000 miles in 1931), and is used as a yardstick in astronomical calculations. It is probable that these tiny bodies are fragments of several larger bodies.

JUPITER (God of the Universe). This great body (Fig. 36) (86,000 miles in diameter) the largest of the planets, is visible in

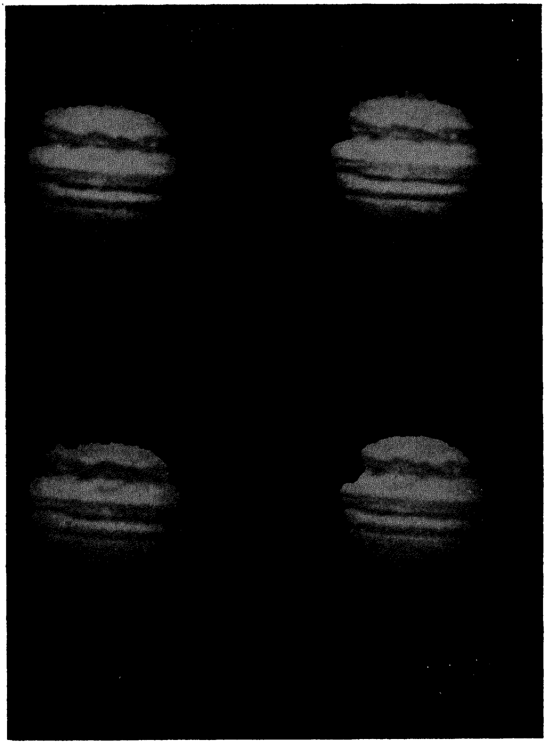

FIG. 36.—Telescopic views of Jupiter. (*Mt. Wilson Observatory.*)

the sky for most of the year and is easily identified by its brilliance. Not much is known concerning the planet. Very recently the spectroscope has revealed that the outer layer of Jupiter is composed mainly of solid ammonia and liquid methane (natural gas). The temperature is very low. It presents a spheroidal shape owing to its rapid rotation. A most interesting feature of Jupiter is the presence of nine moons, two of which revolve in a retro-

grade (backward) direction relative to the others. Galileo found four of these moons by his telescope, thus confirming the theory of Copernicus that the center of the solar system is the sun and not the earth.

SATURN (God of Time). Far beyond Jupiter lies this most beautiful of all planets (Fig. 37). This planet, almost as large as Jupiter (71,000 miles in diameter) and rotating rapidly, is interesting because it is the only object in the heavens that has rings. Galileo noticed a peculiarity about Saturn, but his telescope was not powerful enough to make the rings clearly visible. The

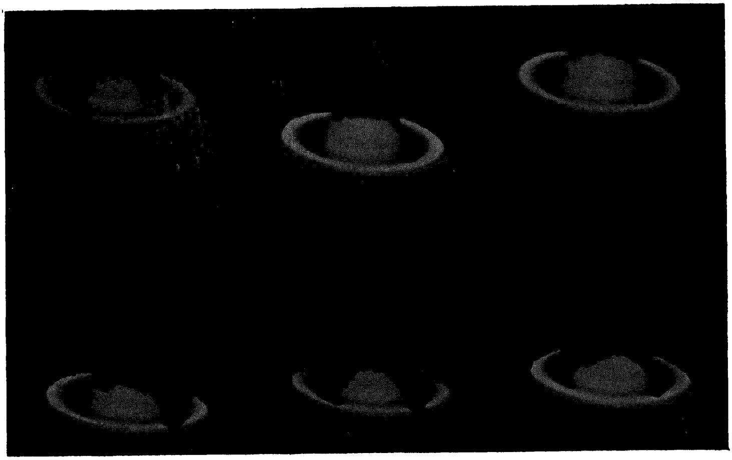

FIG. 37.—Telescopic views of Saturn. (*Mt. Wilson Observatory.*)

rings are now known to be masses of small stones (meteors), each revolving about the planet in its own path. Perhaps they represent moons "spoiled in the making." The appearance in the telescope is that of three sheets of silver. Saturn has nine moons, one of which, Phoebe, revolves in a retrograde direction. These backward motions of satellites prove a serious flaw in the nebular hypothesis of the origin of the solar system (see p. 63).

URANUS. Uranus (32,000 miles in diameter), the next planet in order of distance, was discovered in 1781 by the astronomer, Herschel, and the planet is still called Herschel by some astronomers. He found it accidentally while searching for new comets.

Its appearance is very much like a star and it cannot be seen easily with the unaided eye. Very little is known concerning it except that it resembles Jupiter in many respects. Uranus rotates in a *retrograde* direction. The planet has *four* moons, all of which revolve in a backward direction.

NEPTUNE (God of the Sea). Neptune (31,000 miles in diameter) was made known by one of the most romantic discoveries in science. Two young mathematicians, Adams in England and Leverrier in France, had calculated that the disturbed motion of Uranus was caused by the gravitational power of another body. This would indicate the presence of another planet. Leverrier wrote to the German astronomer, Galle, telling him exactly where it should be found. Galle turned his telescope to the point of the sky and found the planet less than one degree in declination (p. 32) from the indicated spot. The planet rotates in the direct way and has *one* satellite which revolves in the *retrograde* direction. (A satellite is the scientific name for a moon.) The method of calculation involved the subject of *perturbations*.

Each body in the solar system exerts a gravitational force on every other body. The sun attracts the earth, the moon and all the other bodies of the solar system. The earth also attracts each of the other bodies. The result of this is that all the paths are irregular in shape. It was found that Uranus differed from the path which it should have pursued. The inference was that an unknown body was exerting a gravitational pull on Uranus. The body was found to be Neptune.

PLUTO (God of the Underworld). In 1930, the world was startled by the announcement of a new planet. This planet was given the name, Pluto. After the discovery of Neptune, astronomers found that the perturbations of Uranus were still not completely accounted for. Various investigators set themselves the task of predicting the position of another new planet. Percival Lowell was one of the most constant searchers, and it is a tribute to his memory that, although the discovery was not made until after his death, his calculations made the discovery possible. The image of the planet was found on a photographic plate by a young assistant* at the Lowell Observatory. Actually, the planet is very faint and little is known about it.

* C. W. Tombaugh.

COMETS

Among other bodies which are visible at times in the solar system, are several hundred thousand comets. These bodies, noteworthy for their long tails (the word comet means "long haired star") which are often as much as a million miles in length,

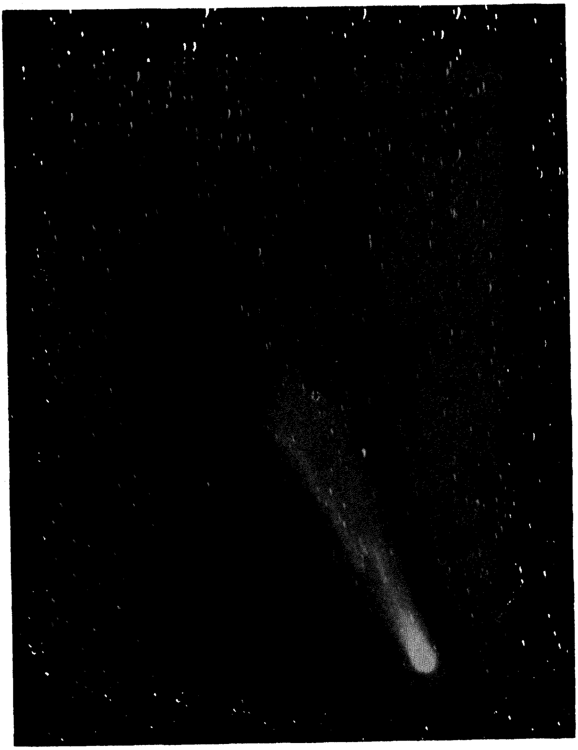

Fig. 38.—Brookes comet. (*A reprint of Yerkes Observatory negative C104. By permission of the University of Chicago Press.*)

move in paths which carry them far out into space, but they are all believed to be a part of the solar system. They consist of gas and small rocks (Fig. 38). Peoples in all ages have been frightened by the appearance in the sky of these curious objects. Halley's comet, which was last visible in 1910, has been noted as far back as several thousand years B.C. Most comets are

faint and the appearance of a bright one is quite unusual. They seem to be harmless and a collision with one might do no harm to the earth. Halley's comet returns every 77 years and most comets seem to return within a century. It is believed that comets are the source of meteors.

METEORS

Space in the solar system contains many rocks. Several million of these rocks enter the earth's atmosphere every day. Most of them are consumed by friction with the air and are called

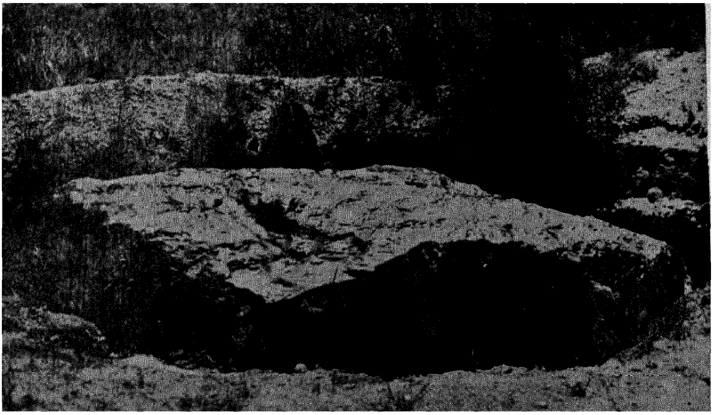

FIG. 39.—Iron meteorite—60 tons. (*Courtesy Natural History Magazine.*)

shooting stars, but a few large ones fall as meteorites (Fig. 39). These meteorites are frequent celestial visitors. There are many references to such subjects in the history of ancient peoples. It is believed that the famous image of Diana was cut from a meteorite. Mohammed placed a meteoric stone in the corner of the Kaaba at Mecca. Several South American tribes worshipped such objects. About 1000 meteorites are in museums. One of the largest collections of meteorites is that of the Field museum in Chicago. As stated in Chapter 4, it is generally believed that Meteor Crater in Arizona was formed by an enormous meteorite. Mention has already been made of the great meteoric fall in Siberia. As far as is known, no meteorite has killed a human being, but in 1930 a

large chunk passed through the radiator of an automobile in Iowa.

There are two types of meteorites. Some are composed of metallic iron and nickel, while others are stony in character. The stony type contains no new elements, but such rocks have contained some unusual compounds such as phosphides. They contain great quantities of gas, but no free oxygen.

THE ORIGIN OF THE SOLAR SYSTEM

Since all the planets are much nearer the sun than is any star, it is practically certain that the sun is in some way responsible for the evolution of the solar system. The most distant planet, Pluto, is less than 4 billion miles from the sun, while the nearest star, Proxima Centauri, is about 25,000 billion miles distant. It is remarkable that all the planets revolve about the sun in the same direction. The sun rotates in the same direction that the planets revolve. The moons, with a few exceptions, revolve about the planets in the same direction as the planets revolve about the sun. Nearly all the planets rotate in the same direction as the sun. Any satisfactory theory of the origin must be able to explain the uniformity of motion.

There are several theories which are worthy of consideration. It must be emphasized that no theory rests on any very definite basis of fact, and that one must consider each with an open mind. Moreover, no theory offers an explanation of ultimate creation.

One of the earliest theories, the *Nebular Hypothesis*, was that of Laplace. This was presented in 1796. Laplace reasoned that the atmosphere of the sun originally extended out to the limits of the solar system, several billion miles. Perhaps the sun resembled a nebula, hence the name of the theory. The body was rotating and was very hot. As the mass cooled and lost heat by radiation, it contracted and, because of the conservation of momentum, began to rotate faster until it threw off a ring of matter from its equator somewhat as mud is thrown from a carriage wheel. This ring of material formed a planet. Other rings were formed as time went on and so the solar system evolved. Theoretically, such gaseous rings could not form spheres, but would remain in a form

like the rings of Saturn. The retrograde motions could not be accounted for. Nevertheless, the theory offered a great field for study and was partly responsible for the work of Darwin on "The Origin of Species."

The theory of Laplace conjectured that the sun by its own motions formed the planets. In contrast to this, we have the two-star theory of Chamberlin and Moulton, two professors at the University of Chicago. In 1900, they advanced the theory that, in the passage of time, our sun came near another star whose

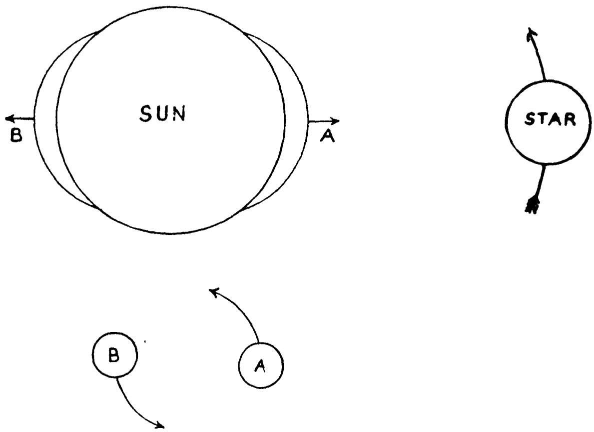

Fig. 40.—The tidal theory of the origin of the solar system.

gravitational pull caused many small bodies to be torn away from the sun. In time these small bodies coalesced into the present planets. This theory is called the *Planetesimal Hypothesis*.

An improvement on the Planetesimal theory is the *Tidal Theory* developed by the astronomer Jeans. The initial idea is that our sun was aided in the evolution of the solar system by the close approach of another star which has since left the vicinity. Suppose that a few billion years ago such a star approached our sun close enough to be in the range of our present solar system (Fig. 40). This star was very large and our sun was a gaseous body. Because of the enormous gravitational attraction exerted by the star, two long prominences were thrown out from the sun. One of these tidal streamers (A) was raised on the side

adjacent to the star, and the other (B) on the opposite side, in a manner similar to the present water tides on the earth. As the star moved forward, the streamers were set into revolution and they coagulated into rotating spheres, the planets. The moons were formed subsequently. The larger spheres absorbed the smaller ones and the solar system slowly assumed the present form. Assuming that this hypothesis provides a substantially

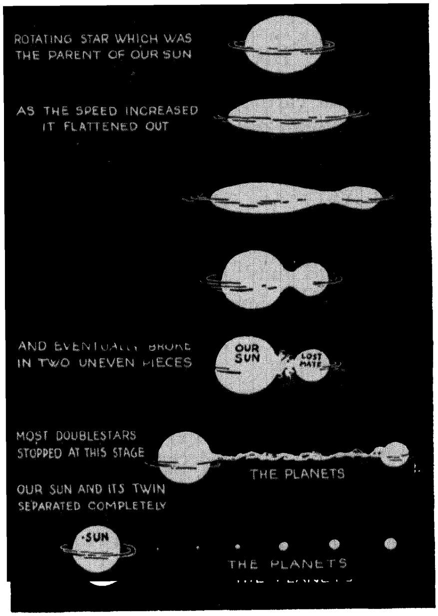

FIG. 41.—The fission theory of planet formation. (*Courtesy Science Service.*)

correct description of the evolution of the planets, the earth grew up around a nucleus by gathering to itself gas and stones. The comets and meteors are bodies which were not absorbed by the larger ones. When the earth became large enough, it began to retain an atmosphere. Sometime after this life appeared.

Two other theories worthy of mention are the *Three Star Theory* and the *Double Star Theory*. Ross Gunn considers the solar system to have been formed by the fission (division) of a very large star into our sun and another star. Between these two bodies, many little bodies remain which form our planets. Many of the

known stars are double and triple stars, a fact that makes this theory a possible solution of the problem of planet origin (Fig. 41).

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PROBLEMS

1. Compare Mars with the earth as to the possibility for the existence of life.
2. Explain clearly the ideas in the theories of the origin of the solar system.
3. Distinguish between rotation and revolution.
4. What are shooting stars?
5. Would it be dangerous for the earth to collide with a comet?
6. Name the constellations of the ecliptic.
7. Why is Venus difficult to study?
8. What do we know about Jupiter?
9. How was Neptune discovered?
10. What is a meteorite?

TOPICS

Meteorites.	The Kaaba at Mecca.	Halley's Comet.
Nebular Hypothesis.	The Fission Theory of Ross Gunn.	Mars.

VISUAL AID

THE SOLAR FAMILY—University of Chicago Film.

EXPERIMENTS

1. Make a distance chart of the planets.
2. Draw the planet faces.
3. Use the Nautical Almanac to find the time of planet appearance for each month of the year.
4. Draw a horoscope for the day that you study this chapter. (For this purpose use the Nautical Almanac and any almanac found in drug stores.)

6

THE EARTH AS A PLANET

> "*Many an Aeon moulded Earth*
> *Before her highest, Man was born.*
> *Many an Aeon, too, will pass*
> *When Earth is manless and forlorn.*"
>
> *Tennyson*

THE MOST important planet to us is of course the earth. Our planet because of its rotation is a *spheroid* and not a sphere. The earth has a diameter of about 8000 miles and weighs about six sextillion tons. It has an atmosphere containing among other gases, oxygen, water vapor and carbon dioxide, the three gases which make life possible (see Chapter 11). Because of the inclination of the axis of rotation to the plane of the orbit, the earth has seasons. It rotates on an axis once in 24 hours, and revolves about the sun at a speed of about 1000 miles per minute, making the complete circuit in about 365 days or a year. It travels in an elliptical path. In this path the earth is *closest* to the sun in *January* (perihelion), and *farthest* away in *July* (aphelion). The difference is about 3,000,000 miles. The earth has one satellite, the moon.

THE SEASONS. One of the most interesting of the phenomena that the inhabitants of the temperate and polar zones of the earth experience is the cycle of the seasons. During the year, the sun *apparently* moves north to the Tropic of Cancer, and south to the Tropic of Capricorn. (In January, Chile and Paraguay are having the hottest weather. People are at the beaches and are wearing summer clothing. In the same month, central United States is experiencing the coldest weather. Conversely, in July the United States has hot weather, and Chile is in the midst of winter.) As a result the temperature varies greatly during the period, causing the seasons. There are three principal causes for the change of seasons. One of these is the variation in the length

of day and night during the year. Secondly, less energy is received on each square mile of area in the winter season, owing to the obliquity of the sun's rays. The third very important reason is that when the sun is low on the horizon, the radiation must pass through a great thickness of atmosphere and, as a result, much of the total radiant energy is absorbed, only a part reaching the earth to produce heat. Consequently, despite the fact that the earth is nearer the sun in January than in July, the northern hemisphere is colder in January.

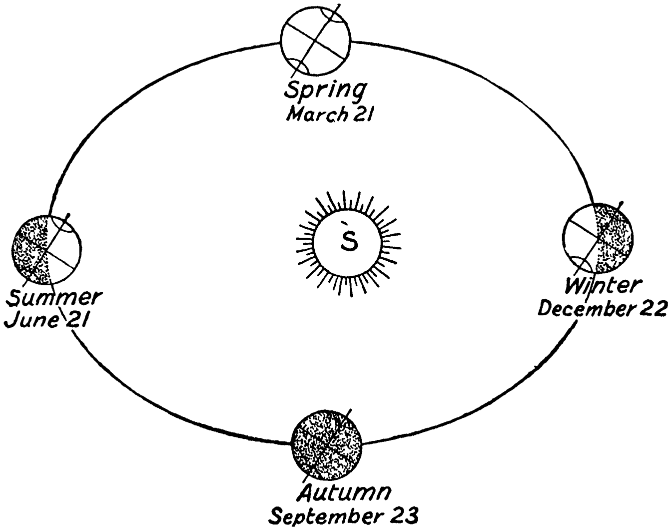

Fig. 42.—The positions of the axis of the earth during the solar year. (*Bowden.*)

Consider a square mile of surface at the Tropic of Cancer. On June 21, when the sun is shining directly on this region, this area receives a certain amount of solar radiation called *insolation.* On December 21, when the sun is shining directly on the Tropic of Capricorn, the rays strike the surface in the region of the Tropic of Cancer obliquely, and each square mile receives less energy.

The earth is rotating on an imaginary axis which is tilted 23½ degrees from the perpendicular to the plane of the orbit (Fig. 42). Its motion resembles that of a spinning top revolving about a point on the floor. On December 22, the north pole is tilted away from the sun, and for several weeks the sun never

illuminates this pole. This is the northern winter. In the northern hemisphere during this period, nights are longer than the days. In the latter part of December, at Philadelphia, 40 degrees north latitude, the day is about 9 hours long; at Winnipeg, latitude 60 degrees north, the day is 8 hours long. During the 15 hours of night at 40° north latitude the loss of heat by radiation out into space is greater than the 9 hour reception of energy. When the earth is at the *equinox* position, the sun shines directly on the equator and the days and nights are everywhere of equal length.

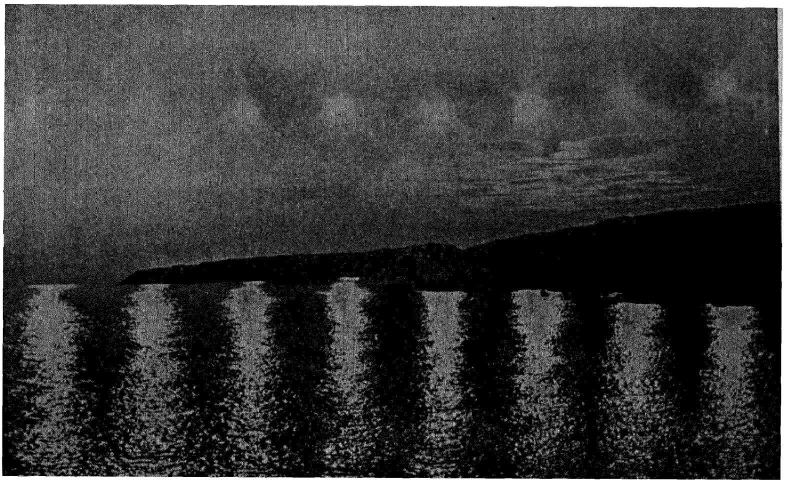

FIG. 43.—The Midnight Sun at Etah, Greenland. Photographs taken at 20 minute intervals. (*Courtesy Baker's "Astronomy," D. Van Nostrand Co.*)

This occurs on March 21, and is the *Vernal Equinox*. Likewise we have the *Autumnal Equinox* in September.

As spring progresses in the northern hemisphere, the sun rises earlier each morning and sets later each evening until June 21. On June 21, we receive radiant energy during the entire 15 hours that the sun is above the horizon. As a result, the temperature of the northern hemisphere is increasing day by day. The altitude of the sun also increases day by day and the sun shines more nearly overhead. Both of these factors raise the temperature.

In June and July, the north pole is tilted toward the sun and is illuminated during the entire twenty-four hour day (Fig. 43). On June 23, Helsingfors in northern Finland has sunshine for the entire 24 hours (Midnight Sun). Even in Denmark, twilight lasts all night during the month of June. Points inside the Arctic Circle cannot celebrate with fireworks on July 4th, because of continuous daylight. However, because of the obliquity of the sun's rays, the polar regions never get very warm except for brief periods.

On the other hand, during the northern winter people inside the Arctic Circle do not see the sun for many days. In a recent article in the National Geographic, the wife of a mining engineer in Spitzbergen describes a winter in those latitudes as a most depressing experience.

Although the northern hemisphere receives its greatest heat from the sun on June 21, this date does not usually represent the hottest part of the year. July and August usually have the hottest weather. During the spring more heat is received than is radiated away and the temperature rises. Some days after June 21, the amount radiated equals the amount received, and after some weeks the temperature begins to decline. The more dense the atmosphere the greater the lag of the temperature of the earth behind the sun's heat. As has been stated, there is very little lag of the temperature on the moon because of the lack of atmosphere there.

EVIDENCE FOR ROTATION

The fact that the earth turns on its axis was suspected by early observers and was predicted by Copernicus, but it was not until 1851 that Foucault performed the experiment which definitely proved the fact. He hung a heavy iron ball by a wire 200 feet long and allowed it to swing over a bed of sand. The pin on the bottom of the ball cut a new path each swing, showing that the earth was turning under the pendulum (Fig. 44). (Another evidence for the rotation of the earth is the direction of the Trade Winds (see p. 159).)

If a pendulum bob is suspended by a wire at a point on the equator and started swinging, there will be no change of path

during the day. No matter what the direction of vibration, this direction will not change. On the other hand, if the pendulum is swung at the pole, the path of swing apparently will change. The bob will trace a new path each swing so that in 24 hours the pendulum bob will *apparently* have changed its path by 360°. Actually, the path of swing does not change, since the point of support is a special mounting which cannot twist the wire.

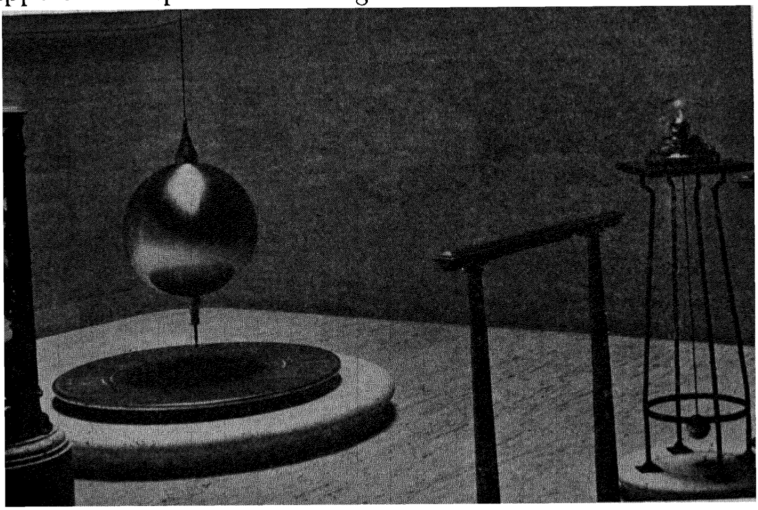

FIG. 44.—The Foucault pendulum at the **Franklin Institute**. The heavy ball is suspended by a wire nearly 100 feet long. At the right is shown a small model of the instrument. (*Photo Gladys Müller.*)

Evidently the room in which the pendulum is mounted is turning around and the sand bed is rotating under the pendulum. At latitudes between the equator and the pole, the change of path depends upon the latitude. This motion has been observed at many points on the earth's surface. We have here the only direct visible proof of the rotation of the earth on its axis.

EARTH STRUCTURE

For convenience we divide the earth into spheres (Fig. 45). The inner sphere we call the *Centrosphere*. Surrounding this is the surface rock layer 40 to 60 miles thick which is called the *Litho-*

sphere. Upon this we find the water layer, *Hydrosphere*, and the air layer, *Atmosphere*. We shall discuss only the centrosphere in this chapter, reserving a treatment of the other spheres for later chapters.

CENTROSPHERE. A study of the interior is, of necessity, based upon indirect information. The older theory of Laplace predicted that the center was a liquid, on which floated the solid crust, like ice upon a lake. Several facts seem to disprove this theory. If a hard boiled egg is caused to spin it will rotate freely, but a fresh egg refuses to spin. The explanation is that the spinning of the soft egg is stopped by the friction of the liquid inside the shell. In the same way, a liquid center in the earth would have caused the earth to stop rotating long ago. Moreover, the crust would not float on top of the liquid, but would sink to the bottom, since solid rock is more dense than molten rock. On the other hand, some studies of earthquake propagation through the center indicate that there is a spherical core about 4000 miles in diameter which is in a plastic state. (Other studies indicate that the core is solid.) Above this lies a layer about 2000 miles thick. Between this layer and the lithosphere is the *basalt* layer. (Perhaps the central core is iron. In Greenland we find great blocks of iron which many scientists believe have come up in lava flow in past ages.)

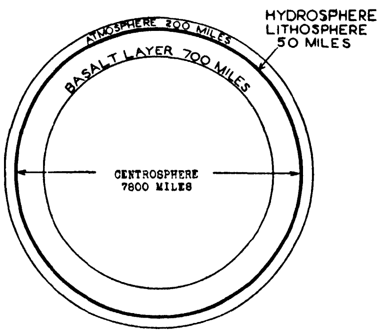

FIG. 45 —The spheres of the earth.

There is general agreement that the center of the earth is very hot. If one goes down into a deep mine the temperature rises as he descends. In deep gold mines, which are over a mile deep, special cooling systems must be provided to keep the temperature low enough for the workmen. Hot springs, geysers, and volcanoes all indicate a high temperature deep in the earth.

THE VOLCANO. A volcano gives us some evidence as to the structure of the *basalt layer*. A volcano is not a smoking mountain:

there is seldom smoke or fire. There issues from the volcano molten rock called lava, as well as steam, dust, and various other materials, including hydrogen, sulfur dioxide, chlorine, hydrogen sulfide, carbon dioxide, and boric acid. The lava is usually composed of feldspars, quartz, mica, and hornblende (see Chap-

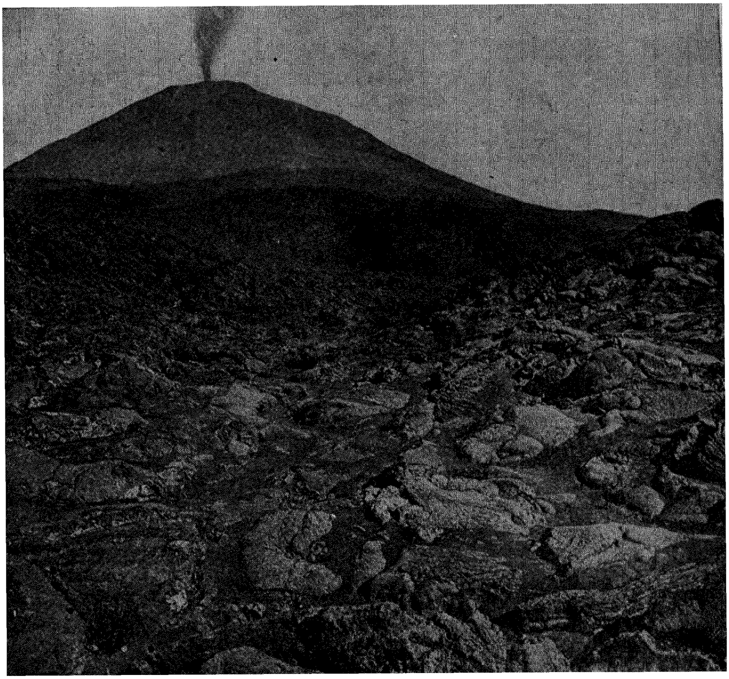

FIG. 46.—Vesuvius under ordinary conditions. (*From Tarr and Von Engeln's "New Physical Geography." The Macmillan Co.*)

ter 9). The only reason that a volcano is a mountain is that it has built itself up by repeatedly pouring out molten rock, which in time forms the cone and later a mountain.

A volcano is a channel which opens up a connection between the basalt layer and the surface of the ground. Probably the cause of the eruption is that the molten rock, which is under tremendous pressure, reaches the surface through channels or faults formed by warping or earthquake faulting. The rock is heated above the

melting point (temperatures of about 2000°F. have actually been recorded in volcanic lavas) but is normally kept solid by the great pressure. When the pressure is released, the rock melts. The violent eruption of a volcano may be compared to the boiling of a pot of mush. As the mixture thickens, the steam will form large bubbles and, if it is not stirred, the mixture will overflow.

Photo by U. S. Army Air Service. © *War Department*

FIG. 47.—Lava-flow, Mauna Loa April, 1926. (*From Tarr and Von Engeln's "New Physical Geography." The Macmillan Co.*)

In like manner, the dissolved gases in the molten rock cause the outrush of lava. There are, in general, two types of volcanoes. There is a type, of which Vesuvius in Italy (Fig. 46) and Pelee in Martinique are examples, which pours out the materials explosively, thus burying and asphyxiating the entire surrounding territory. Another type like Mauna Loa in Hawaii (Fig. 47), pours out lava in a quiet river-like stream. For some years, the

scientist, Jaggers, has maintained a station in the crater of Kilauea in Hawaii. As a result of his observations, often made at the risk of his life, scientists have now a fairly accurate picture of the operation of volcanoes. The word, extinct, is often applied to volcanoes. This is misleading because volcanoes often remain dormant for hundreds of years and then suddenly break forth. Vesuvius was dormant for 500 years before it erupted, burying Pompeii in 79 A.D. There have been 27 volcanoes active since 1920.

EARTHQUAKE STUDY. The best method for investigating the centrosphere is that of earthquake study. An earthquake is the

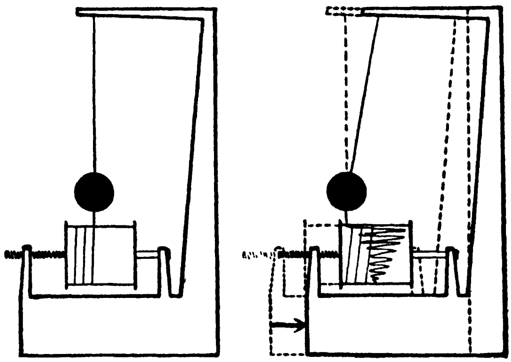

FIG. 48.—The pendulum seismograph. (*Courtesy Professor Lynch, Fordham University.*)

sudden shifting of the earth's crust. Down deep in the earth's crust (lithosphere) there occurs a twist, a fold, or a break in the rock. This occurrence makes the entire earth shake. Since the earth is an elastic body, the quakes travel through the earth like waves in water. For each earthquake there are three quivers. The first is an up and down vibration which travels at a speed of several miles per second. Some seconds later there follows a wave giving a sidewise vibration. Both of these waves travel through the central zone of the earth. Since the sidewise quiver can travel only in a solid, it offers a possible proof that the core of the earth is not a liquid. There is also a wave which travels in the surface rock.

Earthquakes occur frequently in some parts of the world, particularly along the Pacific coast, often causing great disasters.

In the earthquake which occurred at San Francisco in 1906, the vertical wave caused a displacement of more than a foot. The

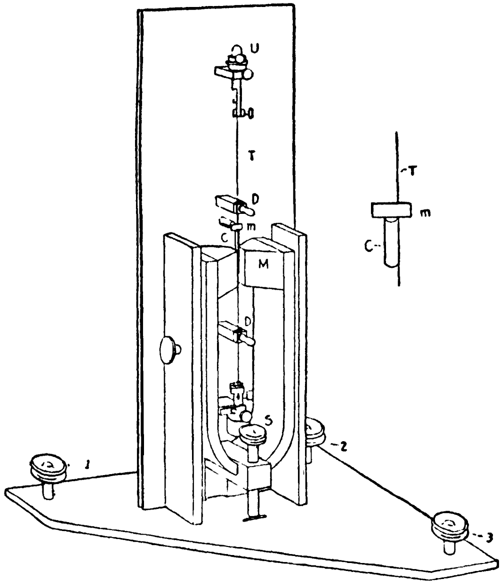

FIG. 49.—The Wood-Anderson seismograph. (*Courtesy Professor Lynch, Fordham University.*)

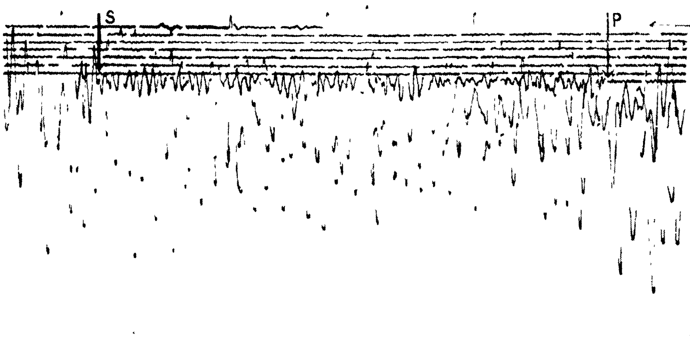

FIG. 50.—A typical seismogram. (*Courtesy Professor Lynch, Fordham University.*)

lateral displacement was as much as 10 feet. This last motion caused the great loss of life. Japan is subject to earthquakes. In

1923, an earthquake occurred which killed nearly half a million people.

Science has devised a very interesting instrument for the study of earthquakes. It is called the *seismograph*. The earlier types of this apparatus consisted of a heavy pendulum hung over a blackened surface. Figure 48 is a schematic diagram illustrating the operation of this type of instrument. When the surface shakes, the drum is set into vibration before the pendulum can get into motion. The result is a wave trace on the moving drum.

The newest type consists of a horseshoe magnet with movable pole pieces. As the pole pieces vibrate they change their position relative to the magnet and a current of electricity is induced in the wire coils wound on the magnet arms. The size of the current depends upon the severity of the quake. Figure 50 is a typical seismogram.

AGE OF THE EARTH

Most scientists believe that the earth grew by absorbing other meteoric material. As the size increased it was compressed and thus became hot. Radioactive material added to the heat. As conditions became suitable gases began to accumulate from the rocks and as a final stage water vapor was formed.

Many estimates have been made of the age of the earth. At best these are inaccurate, but a brief description of some of the evidence will be of interest.

By observing how much material is deposited in the oceans year by year, we can estimate the age of various mud and marl deposits. We can form some rough estimates of the age of a river by observing how much digging it does in a year. Records show that the Horseshoe Falls of Niagara have receded about 5 feet in a year. This makes it probable that the falls are 20,000 years old.

We know that certain rock formations have been developed in certain specific ways. Sandstone has been formed by the cementing of sand particles. Coal beds, by their plant fossils and imprints, indicate that there was at one time a luxuriant flora in marshy land. Limestone has been formed by the accumulation of sea shells and skeletons under water, hence, whenever we find a

limestone layer, we know that the land was submerged beneath the ocean. From such geological evidence we know that North America has been flooded by oceans at least fifteen times since the Proterozoic era (see p. 92).

One of the methods of studying the age of the earth is that of *radioactivity*. Radioactivity is a process in which the atoms of an element go through a process of change and become atoms of a new element. Man cannot influence this natural process by any known means. Only a few elements have this property. We know that the element, uranium (see p. 211) slowly disintegrates and, after a space of several billion years, will become radium and finally radioactive lead. The *uranium-radium-lead* content of the lithosphere is studied and an estimate is formed of the time during which the process has been taking place. Such studies indicate that the earth's crust is several billion years old.

Another interesting method for determining the age of the earth is to study the saltiness of the sea. One can estimate the amount of salt carried by the rivers into the ocean each year, and one can also estimate the amount of sea water which evaporates each year. Assuming that the concentration of salt is increasing year by year, we arrive at the result that the process of making the sea salty has required over one hundred million years.

It is apparent that all these studies lead to the result that the earth is of great age. We have, of course, no direct evidence as to the time which has elapsed since the solar system was evolved. Science has progressed far since the pronouncement of Ussher in 1654 that "creation took place at 9 A.M. on the 26th of October 4004 B.C."

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TOPICS

Volcanic Eruptions.
Earthquakes.
The Foucault Pendulum.
Geysers.
Age of the Earth.
The Midnight Sun.
Mt. Everest.
Seismographs.

VISUAL AID

THE EARTH IN MOTION—University of Chicago Film.

PROBLEMS

1. Give evidence that the earth is rotating on an axis.
2. What is the evidence that the center of the earth is hot?
3. What is the character of the centrosphere?
4. What evidence does an earthquake give as to the character of the centrosphere?
5. What do we learn from volcanoes?
6. Explain why our hottest weather occurs in July rather than June?
7. What is the cause of the Midnight Sun?
8. Give three causes of the changes of seasons.
9. Is it correct to say that the northern hemisphere has winter because it is further from the sun?
10. How can we determine the age of the earth?

EXPERIMENTS

1. Make a field trip to a mine, quarry, road or a railroad cut. Examine the various layers of rock.

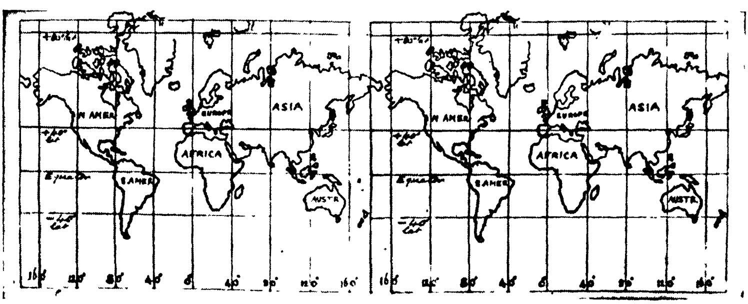

FIG. 51.—A world map. (*Courtesy Professor Lynch, Fordham University.*)

2. Locate volcanoes on the world map (Fig. 51). Connect them with a line. You will find that most volcanoes lie along one of three lines.

3. Make a drawing showing changes of seasons.
4. Try to spin a fresh egg. Why is it difficult?
5. Make a report on some limestone cave in the vicinity.
6. If the building has a stable foundation, hang up a heavy bob as a Foucault pendulum and observe the apparent shift of the plane of rotation. In the temperate zone it will change about 10 degrees per hour.

7
THE EARTH A CLOCK

"*Time and the hour run through the roughest day.*"

FOR AGES man has attempted to use the heavenly bodies to record the time of certain events, such as wars, religious festivals, and great calamities. The two objects which first suggested themselves were the sun and moon. Most ancient peoples and savage tribes have used the interval between two full moons as a measure of time. It is interesting that the word *month* comes from the word *moon*.

The Mohammedans use the lunar year consisting of twelve months, some having thirty days, and some twenty-nine days. The sacred month of Ramadan is the ninth month of the year. Each month begins with the rising of the new crescent moon. Because the moon makes a revolution about the earth in about twenty-nine days, there is not an exact number of full moons in a year of 365 days. There are 12 moons and about 15 days. As a consequence, the month of Ramadan may occur at any season of the year. This is very unsatisfactory.

The Chinese have a calendar consisting of twelve months, to which they add one month in every thirty. Their new year begins with the first full moon after the sun enters the constellation, Aquarius.

Other peoples have used the sun. The Mayas had an elaborate method of timekeeping which depended on the solar year.

SIDEREAL TIME

The earth rotates on its axis in exactly 24 hours *sidereal time* (star time). This means that if, for example, Vega in the constellation Lyra, is on the *meridian* (a line passing overhead from north to south) at 18 hr. 34 min. sidereal time, the star will again be on the meridian exactly 24 hours later. This is the time that is preferred by the astronomer.

Because of the fact that the earth is continually moving around the sun, completing the circuit in a year of about 365 days, the sun, each noon, seems to be about one degree farther east among the stars than it was the day before. The various positions of the sun among the stars are called the *Zodiacal* positions (see p.

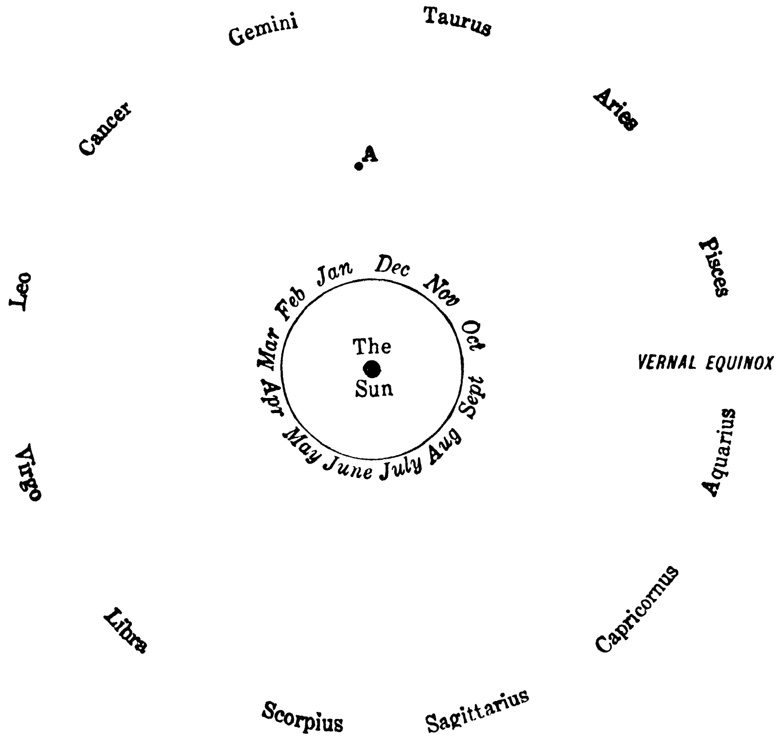

FIG. 52.—A drawing illustrating the sun's apparent motion among the stars. For example, if the earth is in the position marked June, the sun seems to be in the direction of star A. (*From Duncan's "Astronomy," Harper and Bros. Used by permission*)

54). On June 21, the sun is said to be in the constellation Cancer and, on December 22, it is said to be in Capricorn. (It is interesting to remark that the present positions are really Gemini and Sagittarius, because of a shift during the past 3000 years.) This motion of the earth has the result of causing the stars apparently to cross the meridian *4 minutes* earlier each day than on the preceding day, if we reckon by *sun* (solar) time.

In Fig. 52, if the month is June, the sun seems to be in the direction of Gemini; in December, the sun appears to be in the direction of Sagittarius. As the earth moves about the sun, the sun seems to move among the stars.

This effect can be demonstrated by the use of a planetarium and an electric light. The electric light will represent a fixed star when placed some distance from the planetarium. Allow the earth to revolve about the sun, and it can be easily seen that the star seems to rise earlier each evening because of the motion of the earth about the sun.

MEAN SOLAR TIME

Were the apparent eastward motion of the sun uniform, each solar day would be longer than a sidereal day by the same number of minutes. However, the motion of the sun is not uniform, so that the days vary slightly in length. The earth moves in an ellipse, traveling more rapidly in the winter than in the summer. It requires *186* days for the earth to pass from *vernal equinox* to *autumnal equinox* (March 21 to September 22), and only *179* days to return. The earth is nearer the sun in the northern winter and as a consequence is attracted with a greater force, moving more rapidly. Because of this lack of uniformity of motion, we use as our timekeeper not the *real sun, but an imaginary sun which does move along the equator with a uniform speed through the heavens, traveling the same distance each day. This sun gives us mean solar time.*

If each community operated by its mean solar time, time would vary from place to place, as only those places having the same longitude would have the same time. To remedy this, *standard time* was adopted by the railroads in 1884, so that time would change at certain intervals or belts of distance. These belts are irregular and their positions are located to suit business conditions.

LONGITUDE

The meridians of longitude are great circles that pass around (circumscribe) the earth from pole to pole (Fig. 53). Because of the fact that the *mean sun* apparently passes around the earth once in 24 hours, we divide the 360 degrees of longitude into

24 zones of 15 degrees each, one for each hour of the day (Fig. 54). Thus the sun is said to pass over 15 degrees of longitude each hour. By international agreement, the meridian of longitude passing through Greenwich is numbered zero, and the degrees are numbered westward toward the United States, and eastward toward Asia. For example, the longitude of New York is about 75 degrees West, which means that there is a time difference of 5 hours between London and New York. When it is 12 noon in New York it is 5 P.M. in London. Most evening radio listeners are familiar with the sound of Big Ben striking midnight in London. In 1886, Japan made its time that of the meridian 135 degrees East, 9 hours fast from London. The United States has 4 time zones; Eastern, Central, Mountain and Pacific. (Fig. 55.) All communities in a zone observe the same time.

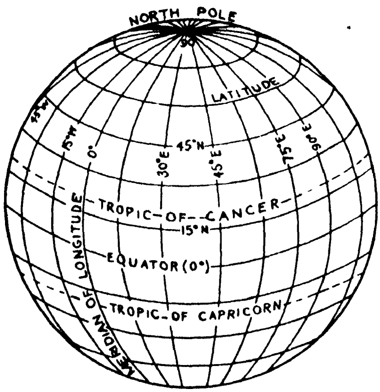

FIG. 53 Longitude and latitude meridians

THE DATE LINE

The two types of longitude meet at 180 degrees, which is called the *Date Line*. The reason for this name will be made clear by examples. If one should make a world tour, traveling westward from Philadelphia, he would need to set his watch back one hour for each of the 24 time belts. The consequence would be a whole day lost on his return. On the other hand, if he traveled eastward, the watch would need to be set ahead one hour for each zone. Upon return from the trip around the world, one day would be gained. Another example may be of interest. Let us imagine an aviator to leave London at noon on July 1, traveling around the world westward at 40° North Latitude, at a speed of 750 miles per hour. At this speed, the sun would always be overhead and, upon return to London, no night would have been experienced, hence no new day. The inhabitants of London would have had

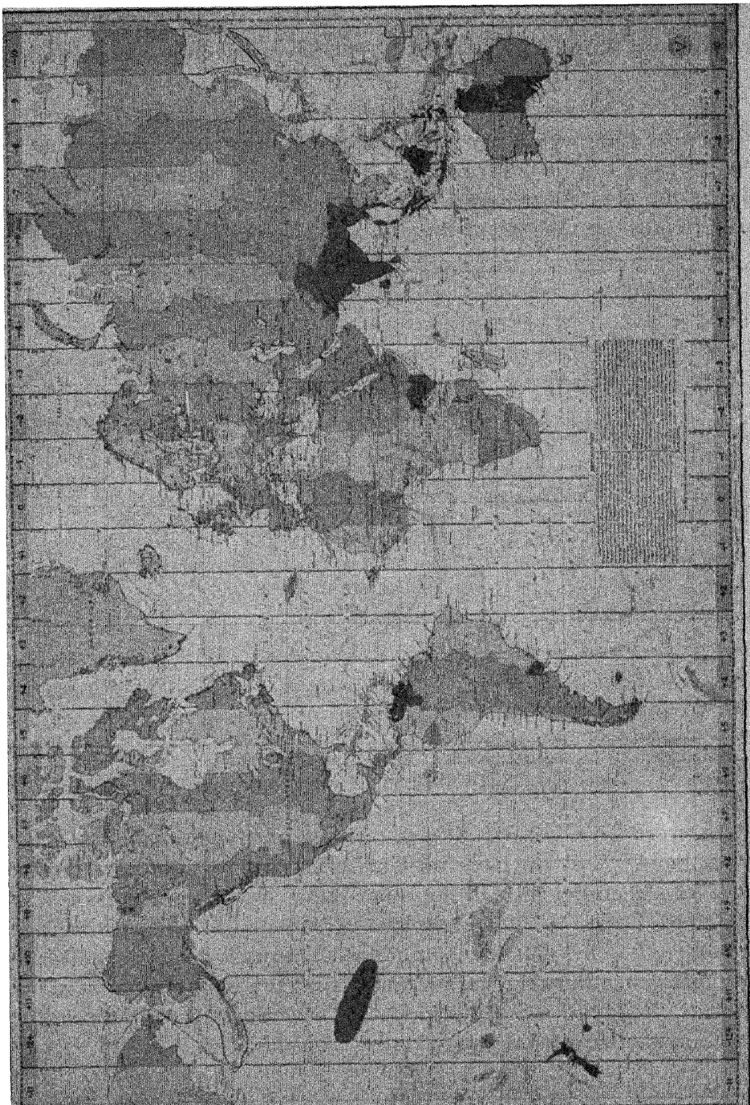

FIG. 54.—Map of the world, showing time zones and date line.

a night and thus a new day, July 2. The aviator is one day behind London.

In order to obviate these difficulties, the 180 degree line was chosen as the meridian where the day begins. This means that New Year's day is first observed on the *westward* (toward Asia) side of the line. Some interesting results of ocean travel at the line arise from the change of day. If a passenger traveling toward

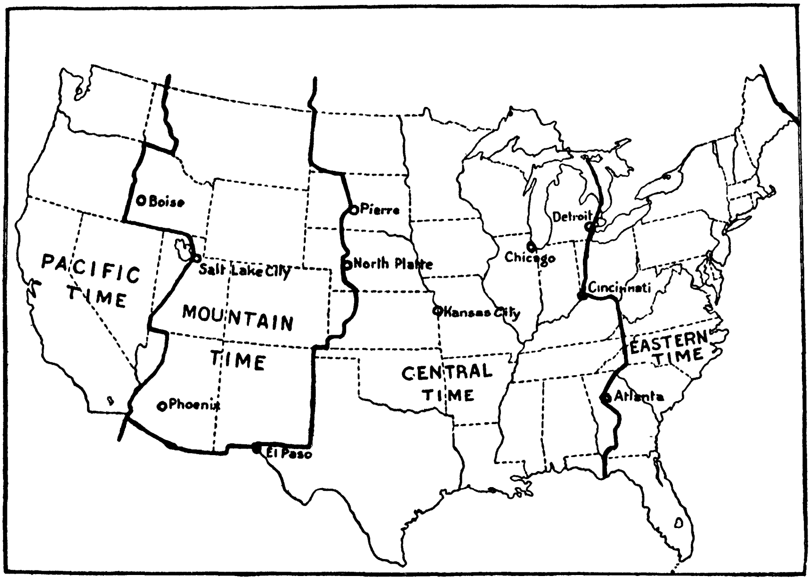

FIG. 55.—Time belts in the United States. (*Map courtesy Stephen Elinsky.*)

Japan from the United States, arrives at the line at 8 A.M. December 25, he will have no Christmas dinner, since the day becomes December 26. On the other hand, if a passenger travelling from Japan to San Francisco arrives at the line at 8 P.M. December 25, he will have another Christmas day. Since the time difference between Japan and New York is 14 hours, 7 A.M. Saturday in Japan is 5 P.M. Friday in New York. We often read on Monday, items from Japan dated Tuesday.

Edgar Allen Poe used the date line as the theme of his short story "Three Sundays in a Week." This story is recommended for reading by the student.

THE CALENDAR

From earliest times man has used some sort of a calendar. As early as 4000 B.C., the Babylonians divided the year into 12 months of 30 days each, and divided the week into 7 days. Somewhat later Egypt constructed a year of 12 months of 30 days each and added 5 holidays. This method was adopted by Greece and Rome but, when Julius Caesar came into power in Rome in 45 B.C., the calendar was in hopeless confusion. In order to rectify the error the astronomers of the time made the year 365 days and added a leap year every 4 years. The months of July and August were added. January was named for the god Janus, February was named for a festival, March for Mars, April for Venus, May and June for lesser gods. July and August were named for he Caesars. We note that September, our ninth month, means seventh. This is a result of the old Roman calendar which began in March.

However, the Julian year is too long by 11 minutes, since the solar year is exactly 365 days, 5 hours, 48 minutes, and 46 seconds. This produces an error of about one day for each century. In 1582, Pope Gregory and his councilors dropped 10 days from the calendar, making October 5 become October 15, and a change was made to correct the error for the future. The Gregorian calendar has the same year and leap years as the Julian calendar, except that the century years 1700, 1800, and 1900 were not leap years. Century years must be divisible by 400. Because of religious difficulties, the Greek and Protestant sects did not immediately recognize the change. However, in 1752, eleven days were dropped in England and America, and January instead of March became the first month. We celebrate February 22, 1732 as the birthday of George Washington, but he was born on February 11, 1732 by the Julian calendar. The Greek church adopted a new calendar in 1923, which differs from the Gregorian.

There are various other calendars, the Jewish, dating from the "creation of the world" 3761 B.C., and the Mohammedan, dating from the Hegira in 622 A.D.

The days of the week are named for Saxon gods, the number 7 being a holy number in ancient religions.

Sunday—Sun.	Monday—Moon.	Tuesday—Tiw.
Wednesday—Woden.	Thursday—Thor.	Friday—Freya.
	Saturday—Saturn.	

One of the great difficulties confronting archeological research is the confusion in numbering the years. Ancient peoples named the year after a certain reign or event. Several hundred years ago, it was decided to begin the era with the birth of Christ.

THIRTEEN MONTH CALENDAR. One of the most serious drawbacks to the present calendar is the fact that the days of the week fall on various days of the month. It would be desirable if Sunday always fell on the first, eighth, fifteenth, and twenty-second of each month. Moses Cotsworth has proposed a 13 month calendar which would make this possible. Each month would have 28 days, with one day called New Year's day, belonging to no month. Many business firms have adopted such a calendar to their bookkeeping.

THE CLOCK

Although the earth's rotation gives us the 24 hour day, to divide this interval we must use other devices. One of the oldest types is the *sundial*, invented by the Egyptians. The obelisk was a form of sundial. Unfortunately, the sundial is of limited use because sunshine is necessary. *The hour glass* was another type of hour divider. It was made by filling a glass bulb with a certain amount of sand or water and allowing it to run out slowly. When the bulb was empty an hour had passed.

Galileo noticed, when watching a swinging chandelier in the cathedral at Pisa, that it retraced its path in exactly equal intervals. It is said that he used his pulse as his time clock. By a series of observations, he established the laws of the pendulum. A pendulum kept at a constant length, and having a constant force of gravity acting upon it, will always execute a swing in the same interval. In order to keep the pendulum at a constant length, methods must be used to keep the temperature from affecting it.

Since most materials increase in length as the temperature is increased, various devices are used to counteract this effect. In one type of pendulum, the bob is partly filled with mercury. As the length of the rod increases, the mercury rises, keeping the effective length the same. Another type uses two metals which

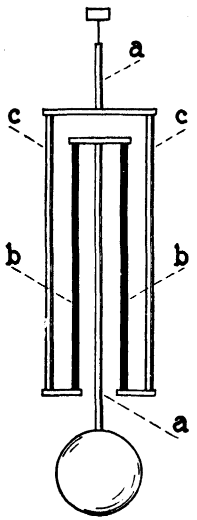

FIG. 56.—A compensated clock pendulum. (*Foley.*)

FIG. 57.—Christian Huygens. (1629–1695.) Physicist and astronomer. Invented the pendulum escapement, originated the wave theory of light.

have unequal expansions. The two expansions neutralize each other. (Fig. 56.)

The time of swing of a pendulum equals $2\pi\sqrt{\frac{\text{length}}{\text{acceleration of gravity}}}$.

A pendulum about one meter long beats seconds in New York.

After the invention of the escapement by Huygens (Fig. 57), the pendulum became a means of keeping accurate time. In the hands of the astronomer, the pendulum clock is a very accurate instrument. Such clocks are wound every minute and the clock is kept in a constant temperature room. The balance wheel of a

watch is also a timekeeper. The newest type of clock, the electric one, depends upon the fact that the electric current which flows in the wires of the house is alternating or reversing its direction many times each second. The clock contains a tiny synchronous motor which keeps in step with the alternations. If the number of alternations (frequency) is carefully controlled at the power house, the electric clock is an accurate timepiece. It has, however, no accuracy of itself.

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TOPICS

Calendars.	Sun Dial.	The Pendulum.
The Feast of Ramadan.	The Chinese Calendar.	

PROBLEMS

1. Why do we use mean solar time instead of real sun time?
2. If it is 4 A.M. Tuesday in Japan, what is the time in New York? 2 P.M. Mon.
3. It is 1 A.M. Monday in London, what is the time in New York? 8 P.M. Sun.
4. 4 P.M. Thursday in Hawaii, is what time in Chicago?
5. Explain the reason for the change of the calendar in the 16th century.
6. If a star rises tonight at 9 P.M. mean solar time, at what time will it rise 20 days hence? 7:40 P.M.

EXPERIMENTS

1. Make a time belt map of the United States.

2. Set up a simple pendulum by fastening a ball to a string. Make the length 60 cm. and record the time of 100 swings. Change the length to 120 cm., and again record the time of 100 swings. What effect does the change of length have on the time of swing? Adjust the length until the pendulum ticks seconds. Measure the length.

3. Use a bottle with a small opening and try to make an hourglass.

4. Set up a sundial by using a sheet of metal on which you have engraved the hours of the day. Decide which direction the pointer must be set to correctly record the hours. Look up the method in the encyclopedia.

8

THE EARTH'S CHANGING CRUST

"There rolls the deep where grew the tree
O Earth, what changes thou hast seen!
There where the long street roars, hath been
The stillness of the crystal sea."
Tennyson

OUR EARTH is not a fixed unchanging body, but is constantly evolving. As we look about us we think of the earth's crust as stable, but a little consideration shows that changes are going on constantly. Only recently, many shore cottages along the Atlantic coast were swept away as the ocean eroded the shore line. Earthquakes also indicate the instability of the crust. It is very probable that the very part of the crust where we live will be entirely changed within a few thousand years. Perhaps it will be under water; a mountain may be thrust up at the location; a sheet of glacial ice may cover it. The lithosphere has undergone great changes during the past few million years.

In the table of geologic ages (Table, p. 92), are noted the *eras* and *periods* of geologic time. An *era* is the longest period of geologic time and it is divided into *periods* or *systems*. A *period* is based upon the geologic divisions according to movements of the earth's crust. It is largely dependent upon fossils. In this table we find that about 400 millions of years were required for the earth to change from a gas to a liquid (*Astral*). Another 600 million years were needed for the development of solid rock (*Azoic*). For other millions of years, during the Archeozoic and Proterozoic eras, rocks were forming. The oldest rocks are named Archean from the Archeozoic era. This era was probably about one billion years ago.

In the Paleozoic era, animal and plant life was developing in the seas. The water must have teemed with animal life, since we find in these rock layers great quantities of fossils.

TABLE OF GEOLOGICAL AGES

(First column figures express duration of time in millions of years, and are merely approximate)

Eras		*Periods*	*Rock Formation*	*Predominant Life*
		Recent	Quaternary	*Civilization*
½ to 1	Psychozoic	Pleistocene	Glacial epoch Great elevation of land in N. America	First true man
		Pliocene		First man-like animal
		Miocene	Soft coal, salt, gypsum, phosphate	Culmination of mammals
19½ to 59	Cenozoic	Oligocene	Extensive volcanic activity	Higher animals Modern birds
		Eocene	Central western plateau formed; Rockies formed	Evolution of primitive mammals
		Cretaceous	Sandstone, conglomerate, clay, western coal	Placental animals Flowering plants
55 to 135	Mesozoic	Jurassic	Sierra Nevada Mts. formed	Birds; reptiles
		Triassic	Sandstone, coal, salt, quartz	Marsupials
		Permian	Appalachian Mts. formed	Land vertebrates
		Carboniferous or Pennsylvanian	Coalbeds formed; sandstone, shale, limestone in Mississippi valley	Reptiles; insects
150 to 355	Paleozoic	Devonian	Shale, sandstone, Penna. oil sands	Amphibians; great forests
		Silurian	Sandstone, salt, shale limestone, hematite	Lung fishes; air breathing animals
		Ordovician	Limestone	Fish; vertebrates
		Cambrian	Limestone, shale, sandstone	All invertebrate phyla
		Killarney	Sedimentary	No stratified rock No fossil remains
125 to 650	Proterozoic or Algonkian	Keweenawan	Sedimentary	1st known animals: protozoa, sponges, euripterides
		Animikian	Sedimentary	Primitive plants
		Huronian	Slate, quartz, limestone	1st known plants: bacteria, algae
		Algoman		No fossils
		Sudburian		No fossils
		Laurentian	Crystalline Igneous	
150 to 650	Archeozoic	Keewatin	Possibly some sedimentary	
		Grenville	Oldest rocks; limestone formation	
600	Azoic	Development of solid ball by accumulation of meteors		
400	Astral	Condensation from gaseous to a liquid ball, which forms our present core, or centrosphere		

During the Silurian period we find limestone deposits extending through central United States. Such deposits indicate that this region was a semi-tropical ocean having much animal life. The conditions were probably much like the coral regions of the Pacific ocean at the present time. As this water evaporated, it deposited great beds of gypsum and salt. We find these deposits as beds of rock in central New York, northern Ohio, and southern Michigan.

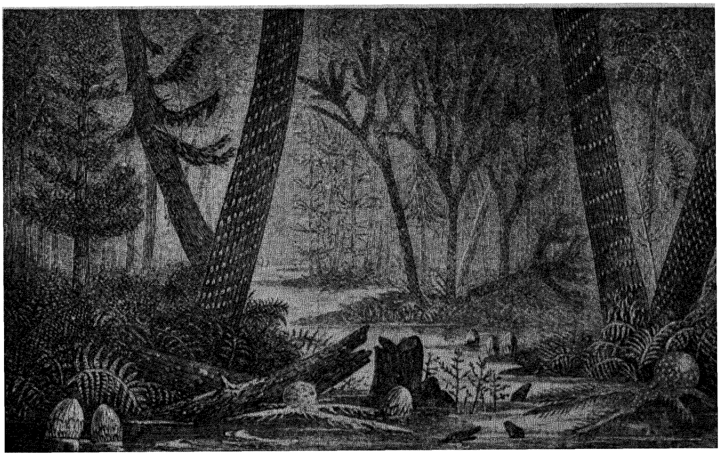

FIG. 58.—An artist's drawing of a coal forest. Such scenes were probably common in the coal forming periods. (*Bowden*.)

Later came the Carboniferous or Pennsylvanian period in which the great coal measures were formed. The coal contains twigs, leaves, and bark, making it easy for us to identify the type of plant that formed coal. As these great ferns fell in swamp land, the water prevented oxidation and the carbon of the plants separated as coal (Fig. 58). The semi-tropical climate necessary for coal formation must have extended over most of the earth. It is startling to find coal in such extreme latitudes as Spitzbergen and the Antarctic!*

The middle era is called the Mesozoic. This age lasted for several hundred million years. This is the age of such reptiles as

* It is estimated that coal was formed at the rate of one foot per century.

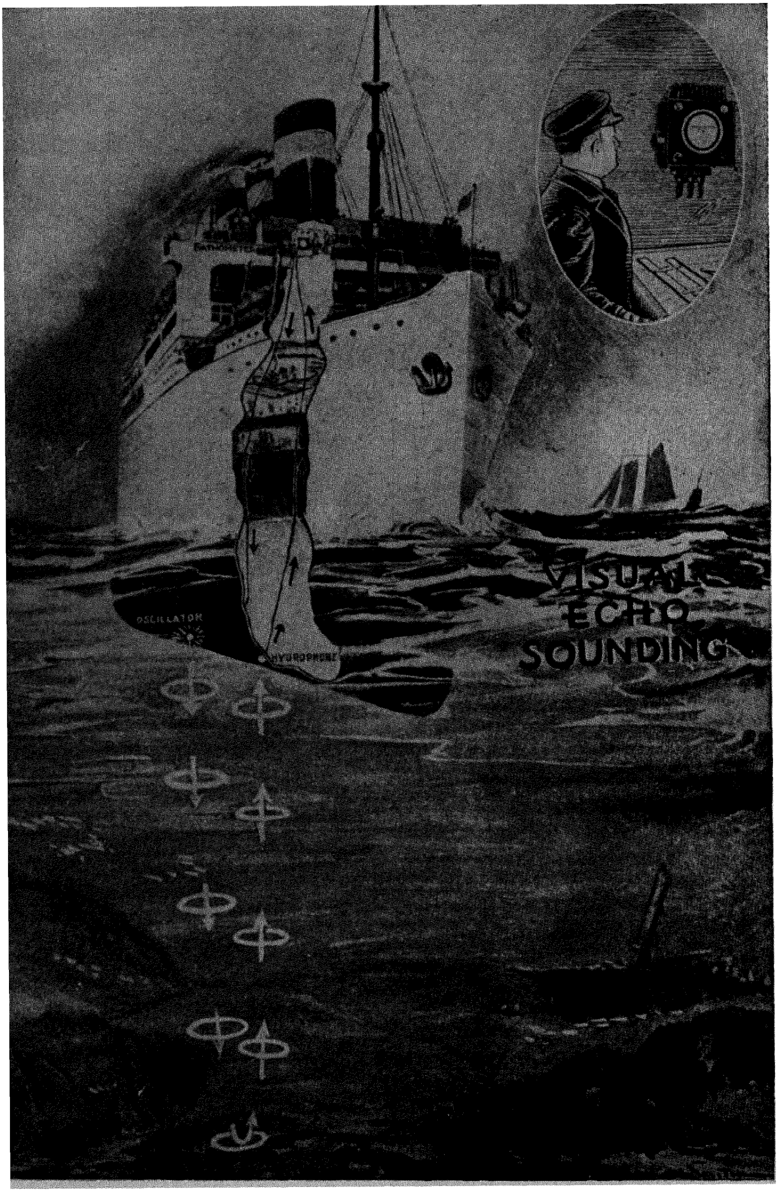

FIG. 59.—Visual echo sounding. Black arrows indicate electrical impulses. White rings and white arrows indicate sound waves. (*Courtesy Canadian National Railways Magazine.*)

the diplodocus. In the Triassic period of this era we find evidence of marsupials such as the kangeroo.

About 50 million years ago, in the Cenozoic era, mammals appeared on the earth, but not until less than one million years ago (the Psychozoic era) did man appear on the scene.

THE HYDROSPHERE

The water envelope of the earth is called the hydrosphere. This term includes the oceans, lakes, rivers, and underground water as well as ice caps. About 72 % of the earth's surface is covered by water.

THE OCEANS. Most of the earth's surface is covered by great bodies of water called oceans. The average depth of the oceans is about 2½ miles. There are, however, great extremes of depth, one of the deeps being Blake deep (28,300 feet) in the Atlantic, and Swire deep (35,000 feet) east of Japan. Inasmuch as the highest mountain is only about 29,000 feet, one can say that the deeps are greater than the heights. If all the mountains and hills were worn away so that the earth was a smooth ball, water would cover the entire earth. The ocean deeps are now being studied by depth-sounding apparatus (Fig. 59). A sound wave is sent down from the vessel and the time is noted for the sound to return after being reflected from the ocean bottom. This makes it possible for a vessel to map the entire ocean floor as it moves along. We now know the contour of much of the ocean bed.

OCEAN DRIFTS AND CURRENTS. Some of the interesting features of the oceans are the *drifts* or masses of water which flow in the ocean somewhat like rivers (Fig. 60). One such drift is the rather large circular movement of water in the Atlantic ocean in the region of the equator. The water, being heated over the equatorial region, expands and flows along the surface of the ocean. The Trade Winds in turn blow the water westward. Because of these two forces the drift flows toward Brazil, where it divides, some flowing north and some south. A portion of the North Drift is warmed further in the Gulf of Mexico and passes up the Atlantic Coast as the rapidly moving Gulf Stream. Upon reaching the belt of Prevailing Westerlies, the Gulf Stream is directed eastward,

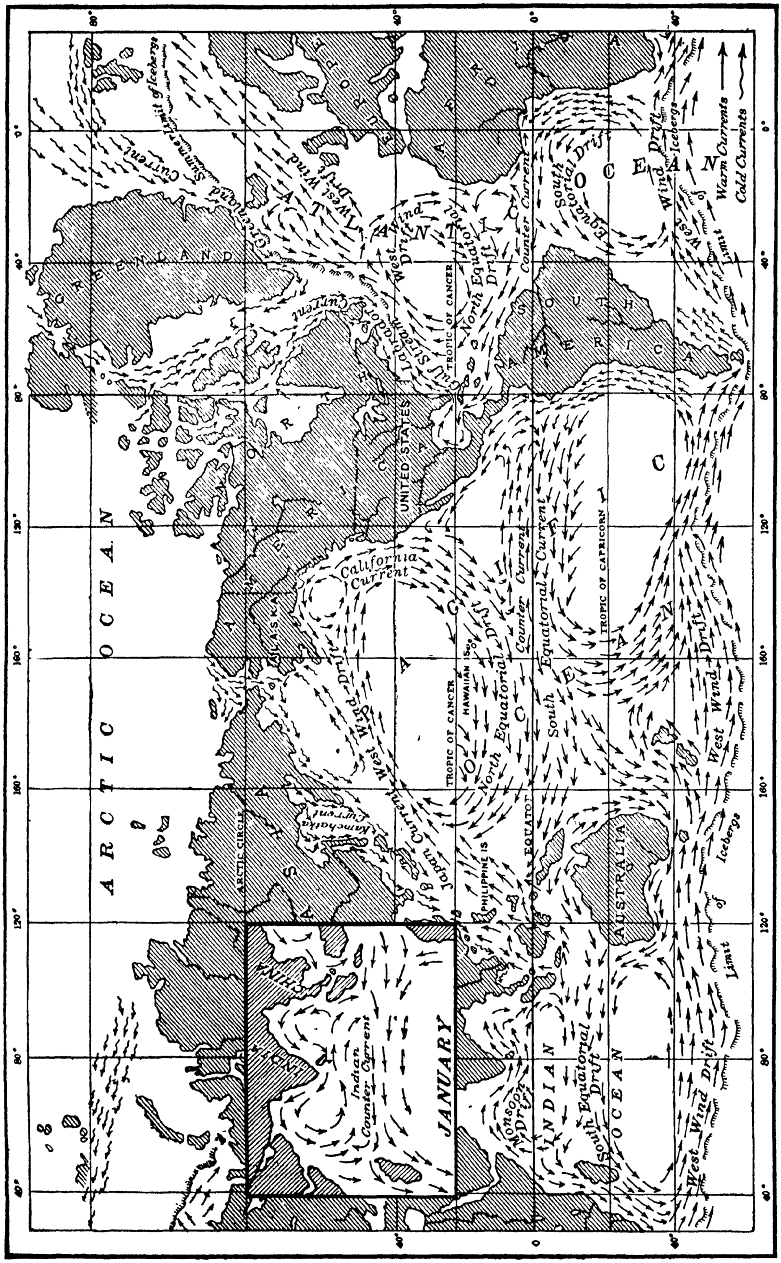

FIG. 60.—The ocean currents and drifts. (From Tarr and Von Engeln's "New Physical Geography." The Macmillan Co.)

part flowing past the British Isles and the remainder flowing past Spain as the Canaries Current. The maximum speed of the current in the vicinity of Florida is about 4 miles per hour and its temperature is about 80°F. This North Atlantic current is very important and has a great effect upon commerce by providing a mild climate for the British Isles, France and Spain. A study of the map reveals that there are regions in all of the oceans where the water has little motion. The region in the North Atlantic is called the Sargasso Sea, a region dreaded by mariners in the days of sailing ships. Another famous current is the Japan Current in the North Pacific, which flows across the ocean from the Philippine Islands. This current moderates the climate along the west coast of North America.

COLD DRIFTS.—There are also movements of cold water which complete the cycle of ocean movement. The dense water of the Arctic Drift flows around Greenland, past Labrador, and drops to the ocean floor as it moves under the Gulf Stream. This cold water flowing past Labrador makes that land very inhospitable, although its latitude is that of the British Isles. Newfoundland and Quebec have a cold climate, despite the fact that the latitude is that of France. The fogs off the coast of Newfoundland are caused by the *cold drift* meeting the Gulf Stream. Alaska is cooled by a flow of cold water.

GROUND WATER AS AN EROSIVE AGENT

Water is evaporated from oceans, is blown over the land and is precipitated as rain or snow. About one-third of this runs off and returns to the oceans by rivers. Another third evaporates into the atmosphere. The balance seeps into the ground and is called underground water. Such water may exist at depths of several miles. The upper limit of saturation, known as the water table, may be at the surface, as in marshes, or 200 feet or more beneath the surface in deserts.

One important feature of ground water is its solvent action and deposition. Because of the great pressures far beneath the surface of the earth, water dissolves minerals which are insoluble under the ordinary conditions. Limestones and silicates will not

dissolve in pure water, but will go into solution if the water contains other compounds. Limestone caves are formed by the action on limestone of water carrying carbon dioxide in solution. As this mineral-laden water flows into cracks or over rock strata, the minerals are deposited in the form of stalactites (icicle-like forms hanging from the roofs of caves) and stalagmites (pinnacles built up from the floor) (Fig. 69). The beautiful deposits in Yellowstone Park were formed by the deposits from ground water (Fig. 61).

FIG. 61.—White Velvet Spring, Yellowstone National Park. (*The Geological Survey and W. H. Jackson.*)

Another very interesting example of the action of mineral-laden water is the petrified forest of Arizona. In this region trees seem to have fallen into a great prehistoric lake where they became water-logged with water which contained silica in solution. As the trees decayed the wood fiber was replaced by silica (quartz), so that today we find these marvelous quartz trees lying about. Figure 62 shows one of these great petrified trees.

Sometimes the ground water accumulates between rock layers under pressure and spouts to the surface in the form of artesian wells. If the rock layers are hot, steam may form in these

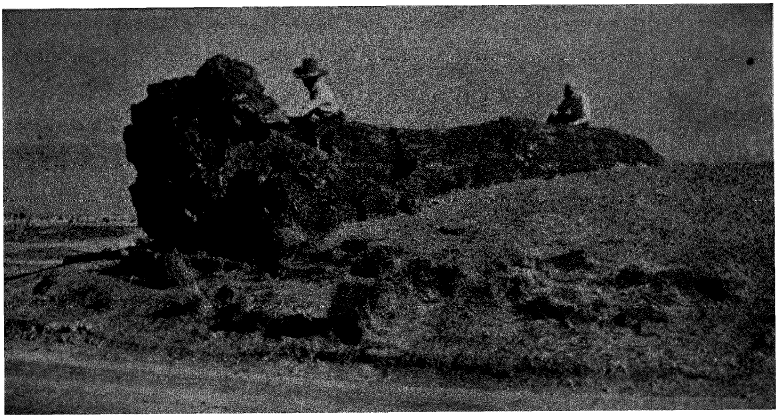

Fig. 62.—A tree in the petrified forest of Arizona. (*Courtesy Atcheson, Topeka and Santa Fe Railway.*)

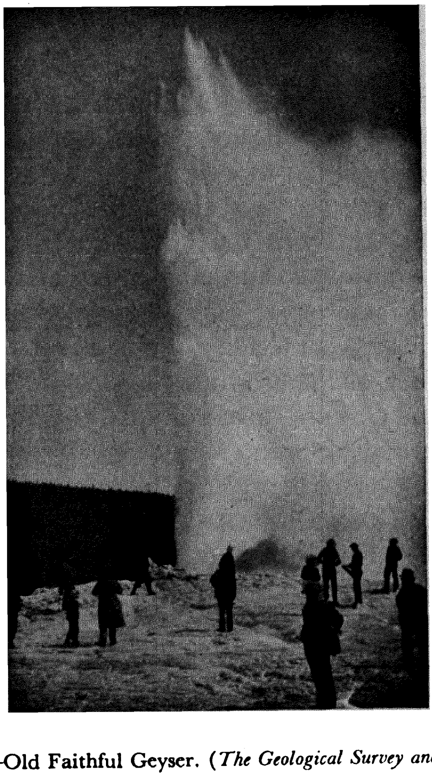

Fig. 63.—Old Faithful Geyser. (*The Geological Survey and W. H. Jackson.*)

underground pockets and force the water upward as a geyser. Everyone is familiar with the story of "Old Faithful" in Yellowstone Park. This geyser pours out a great quantity of water at quite regular intervals (Fig. 63). Some geysers force the water to a height of several hundred feet. There are many geysers in Iceland and New Zealand.

EROSION BY RUNNING WATER

Probably the most important factor in the changes of the earth's crust is running water. We are all familiar with the roadside gullies that form during a heavy rain. Many a farmer finds that his hillside soil is being swept away by torrents of rain. All streams and rivers are constantly carrying fine rock materials to the sea. The Mississippi and its tributaries, the Missouri (Big Muddy), and the Arkansas carry thousands of tons of clay and sand to the Gulf of Mexico every day. The delta formed by this deposition of suspended material grows very rapidly and is a constant problem to navigation. The lower Amazon always has a yellow color due to the immense amount of suspended material which it sweeps along. At Macao, in China, it is necessary to dredge the channel of the Pearl River every few months so that steamers can pass. The Nile River forms islands and wears away others in a single day. This constant transportation of soil materials has denuded many areas such as those in northern China. Other areas acquire great fertility by this circulation of water.

As an example of the erosive action of running water, one must mention the Grand Canyon of the Colorado River. In this region the torrential Colorado has cut great gashes over a mile deep in solid rock. Here the river often carries great boulders as it sweeps along its channel.

GLACIERS

These form another part of the earth's hydrosphere. Snow falling on high mountains is not totally removed each summer by melting, so that it accumulates as deposits of snow and ice. Some of these accumulations are small in area and are seen as small patches on the mountainside. Some, however, become large ice

rivers hundreds of feet thick, gradually moving down the side of the mountain, thus feeding the lakes and rivers at the foot. Other glaciers slowly move toward the sea, at which point pieces break off and float away as icebergs. The Alps are famous for their great glaciers. The Greenland and Antarctic continents are both covered with enormous caps of ice.

It was early noticed that much of the land in North America and Europe was covered with a heterogeneous assortment of boulders and small rounded or polished rocks which were unlike the rock strata of the region. For example, the red granite of the St. Lawrence valley was found as boulders in southern New York state. Moreover, there were peculiar rounded hills, and small potholes and lakes scattered over the region. The famous geologist, Agassiz, assumed that these deposits were the result of widely extended glaciation. He assumed that in the Pleistocene geologic period, great ice sheets had spread southward over Canada and the northern part of eastern United States and over northern Europe. These glaciers gathered a great quantity of rock from one region and scattered it over another section as they melted. The Adirondacks of eastern New York are rounded as a result of glacial action. The thousands of lakes in Minnesota and Wisconsin are of glacial origin. The layers of glacial drift teach us that there were four glacial periods within one million years. Evidently the glacial epochs were periods of cool climate. Between these periods of rather low temperature, there were intervals of semi-tropical climate. The last glacier is believed to have receded about 25,000 years ago.

There is no satisfactory explanation for these ice sheets. We find great mammoths buried in the ice of Alaska. There is evidence of an old ice sheet in the equatorial zone. All our evidence indicates that climatic conditions differed at various periods in the past. Some authorities believe that the carbon dioxide content of the atmosphere increased in some way. This could cause a change in climate by the absorption of a greater portion of the sun's rays. A small decrease in the energy received from the sun could, over a long period of years, produce such a climatic change. Other speculations include a change in the tilt of the earth's axis. There

is, however, no certain evidence that either of these changes took place. The cause of glaciation is still a mystery.

WIND EROSION

A strong wind carrying sand is a very active eroding agent. Automobile travelers in a desert sometimes find that the windshield has been etched by the force of the wind-blown sand. Desert trails are covered with sand in a few hours during a sandstorm. Most people in Central United States have experienced

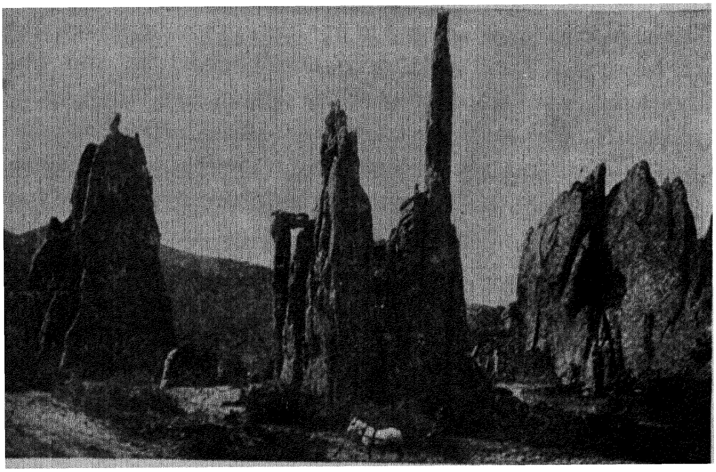

FIG. 64.—Garden of the Gods.

the effects of sandstorms. In Kansas and Colorado great areas of land, called the "Dust Bowl" areas, have been denuded of their top soil by wind storms in recent years (1934–1935). This material has been carried to other regions where it has increased the fertility of the soil. The Bad Lands of the Dakotas derive their peculiar form from the erosive action of the wind. Travelers in the Rockies are familiar with the Garden of the Gods which has been carved by wind blown sand (Fig. 64).

Other erosive agents are chemical processes, plants and animals. Some rocks, such as limestone and serpentine, weather because of chemical action of the atmosphere. As rocks disintegrate, the fine particles are carried away as soil. Rock is a rather poor

conductor of heat, so that it is split by successive heating and cooling and by frost. Plants thrust their roots into crevices in rock and split them apart. Small animals burrow into the holes in the rock.

SOIL

A little crystal of sand could tell us a fascinating story as we play on the beach at the seashore. Hundreds of millions of years ago it was probably on the shore of another ocean. As time rolled on, the small crystal became covered with other sands blown or washed over it from nearby hills. Gradually, it became cemented to other sand grains thus forming a soft sandstone. Perhaps the shore became submerged beneath the ocean as the restless earth wrinkled its surface. A layer of mud which was deposited over it changed to shale, which was in turn covered by a layer of sea shells, the process occupying millions of years.

As the earth's surface continued to change, our sandstone was folded in deeper and deeper; high temperatures melted it. More untold ages passed, bringing with them a gradual uplifting of the highly heated sandstone. As it rose it cooled, still under tremendous pressure, until finally the sandstone became part of the igneous rock, granite. Perhaps the granite formed a great mountain range. Later the conditions of temperature and pressure became such that the granite became metamorphosed into gneiss. Still other millions of years passed during which time the mountain was attacked by various weathering agents, the rock crumbled, hidden rock layers became exposed and disintegrated into sand. Rains and streams gradually returned the sand to the seashore, completing our cycle.

Soil, the material which makes plant growth possible, is formed by the disintegration and decomposition of rock and by the accumulation of plant and animal remains. Weathering agents change rock into soil. These agents may be classed as chemical and physical. The chemical erosion agents change the rock materials into other substances. Oxygen changes iron to its oxides and changes feldspar to kaolin (clay). Water aids in the oxidation of iron; it unites with some granites causing them to

break down; it reacts with some calcium and magnesium rocks. Carbon dioxide, especially in the presence of moisture, reacts with limestone, iron, and other rocks.

Soils also contain plant and animal materials. These include decaying plants and animals as well as the materials given off by them in the living condition. Phosphates and nitrogenous compounds are the principal materials of organic origin. Limestone soils are usually very fertile. Feldspars contribute sodium, potassium, calcium, magnesium, and iron to the soil. A good soil should be a mixture of sand, clay, humus, lime, and soluble substances for plant food. One very valuable soil is called *loam*. Good loam should contain about 30% clay, 50% sand, and 20% humus and plant foods. If the clay of the soil is excessive, the soil is compact and wet so that it is difficult to drain. On the other hand, a sandy soil permits the water to drain away rapidly, so that in periods of dry weather the crops wither from lack of moisture. Plants derive all their food materials except carbon dioxide from the soil. The necessary elements include calcium, carbon, hydrogen, iron, magnesium, nitrogen, oxygen, phosphorus, and sulfur. Certain soils which do not contain enough of the desired elements form poor or "barren" soils. Sandstone and serpentine are typical of this class of soil rock. Soil that is very rich in decaying plant material is called humus.

In addition to these materials there are millions of bacteria and fungi in the soil. These organisms break down manure and other fertilizers, consisting of plant and animal remains, into materials which the soil can utilize. One of the most important types of such bacteria is the nitrogen fixing bacterium. This type lives on the roots of legumes such as beans, peas, clover, and alfalfa. As this type grows it absorbs nitrogen from the air and change it by chemical action into proteins. These proteins provide nitrogen for the plants. For this reason, farmers often plant a crop of such plants to make the land more fertile.

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PROBLEMS

1. What is meant by a geologic age?
2. What is a geologic era?
3. Describe some of the eras.
4. Explain the formation of coal.
5. What is an ocean drift?
6. What is the cause of the Gulf Stream?
7. Explain the formation of a geyser.
8. What evidence is there for ice ages in North America?
9. What are the causes of the formation of soil?
10. What constitutes a fertile soil?
11. What is the most desirable soil and why?

TOPICS

Soil Formation.	Glaciers.	Nitrifying Bacteria.
The Grand Canyon.	The Bad Lands.	Byrd in the Antarctic.

VISUAL AIDS

SOIL FORMATION—Eastman Classroom film.
Films of the University of Chicago.
"The Mining and Production of Anthracite," Anthracite Industries, Inc.

EXPERIMENTS

1. Make a tube of loam, one of clay soil, and one of sandy soil. Study the rise of water in the various tubes. Decide which is the best type to preserve the water level in the field.

2. Make a list of the various warm currents and cold drifts. See if you can predict the climate for the adjoining land.

3. If you can visit a limestone cave, study the rock formations.

4. Examine the gully formed by a violent rainstorm.

5. The biology department can furnish you with root nodules on which are nitrifying bacteria. Examine the nodules closely.

9
ROCKS AND MINERALS

"To the solid ground of Nature trusts the mind that builds for aye."
Wordsworth

THE ROCK sphere of the earth is usually termed the *lithosphere*. This layer, about 50 miles thick, contains the rocks, minerals, and gems which we shall study in the present chapter.

MINERALS

Minerals are chemical compounds. When grains of these minerals are cemented together, they constitute the materials which we call *rocks*. In order to study minerals, the scientist has devised a series of tests by which various compounds can be identified. Some of these tests include hardness, malleability, cleavage, color, streak, fluorescence, and chemical tests.

HARDNESS. A scale of hardness is used by the scientist. Ten representative minerals are arranged in the order of their ability to scratch other minerals.

10 Diamond (hardest)	5 Apatite (scratched by steel)
9 Corundum (scratches topaz)	4 Fluorite (easily scratched by steel)
8 Topaz(scratches quartz)	3 Calcite (scratched by a cent)
7 Quartz (scratches glass)	2 Selenite (scratched by thumb nail)
6 Feldspar (scratched by glass)	1 Talc (soft)

Any mineral in the table will scratch any of those below it in the table. (It is important to emphasize that hardness has no connection with brittleness.)

CLEAVAGE. If one tests a specimen of rock salt by striking it a sharp blow with a knife, the mineral will cleave or slice into rectangular segments, or small cubes. Because of this fact, rock salt, in common with many other minerals, is classed as a cubic

crystal form (Fig. 65). Some minerals, such as calcite, will split into rhombs (Fig. 66). Still others, for example mica, will cleave

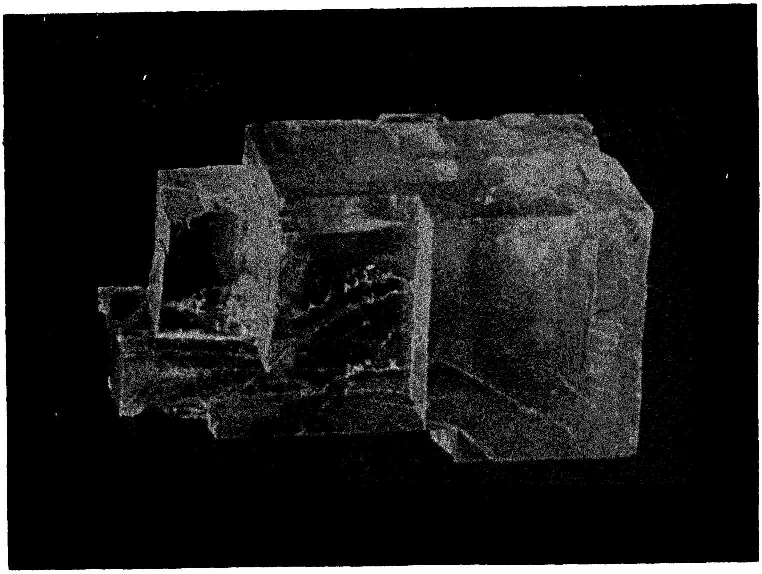

Fig. 65.—Rock salt, cubic crystals. (*English, "Getting Acquainted with Minerals," McGraw-Hill Book Co.*)

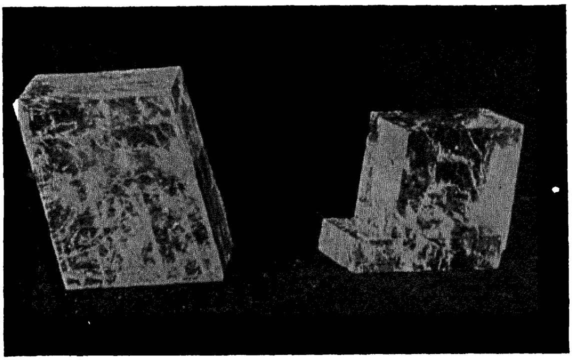

Fig. 66.—Rhombic crystals. (*English, "Getting Acquainted with Minerals," McGraw-Hill Book Co.*)

into thin sheets. By a study of the angles between split surfaces, the mineralogist can identify many of the common minerals. The study of the crystal form constitutes the subject of crystallography.

COLOR. Many minerals have a definite color--copper sulfate being blue, fluorite a purple, quartz having a number of characteristic colors. However, the beginner must use the color test with caution, since many compounds have varying colors.

STREAK. Many minerals leave a streak when rubbed on a white tile plate, such as a floor tile. It is curious that the streak color may bear little resemblance to the surface color of the mineral. Many of the *ores--minerals from which the metals are obtained*--have characteristic streaks. Noteworthy among these are the lead, zinc, and iron ores.

FLUORESCENCE. This is a phenomenon which has recently become very important in mineral tests. Many rocks when illuminated by ultra-violet rays, emit beautiful colors, which in some cases absolutely identify the stone. Some of the most interesting are *willemite*, which fluoresces green; some of the calcites, which give red; and some fluorites, which shine with a blue-green color when illuminated. There is at present on the market a small argon glow lamp which can be screwed into the electric lamp socket. This lamp gives enough ultra-violet for a study of fluorescence. However, the best source of ultra-violet is a mercury arc in cobalt-nickel glass. By using such a lamp, one can produce remarkable fluorescent effects. Every student of minerals should study some of these colors, if for no other reason than the pure beauty of the display.

CHEMICAL TESTS, while very reliable, are rather complicated in most instances. An exception is the acid test for limestone and dolomite, which will be described at a later point of the chapter.

GEMS

Minerals which possess the characteristics of beauty, rarity, and cleavage, are classed as gems. The most famous type of gem is the diamond. This gem has been known from the earliest dawn of history. Diamonds are found in volcanic pipes, mixed in a peridotite rock, and are pure carbon crystals. Most of them are transparent, a few being blue, and some black (Fig. 67).

Diamonds have been found in India, South Africa, Brazil, and in some parts of the United States, notably Arkansas. At present, the most prominent source of diamonds is South Africa. The production and sale are rigidly controlled by the syndicate which operates the diamond field.

As has been noted, the diamond is the hardest mineral known. Besides being used as a gem, it finds much use in rock drilling, as

FIG. 67.—A diamond in its matrix. (*English, "Getting Acquainted with Minerals," McGraw-Hill Book Co.*)

a die for drawing tungsten lamp filaments, and in grinding operations.

For many years scientists have attempted to produce diamonds in the laboratory without success. Just recently a report has come that a practicable method seems to have been devised. Perhaps we may soon have artificial diamonds.

The history of some of the great diamonds is very interesting. We shall describe only a few of the most interesting gems, and refer the reader to the references for a fuller description.

The largest diamond ever found was the Cullinan diamond, which weighed more than a pound in the rough state. Since a diamond has little beauty in the natural state, the Cullinan was cut into a large number of smaller stones, which are a part of the crown jewels of Great Britain.

Many diamonds have adorned idols, whence they were stolen and passed from hand to hand, often accompanied by murder and violence. Some famous gems are the Kohinoor (Mountain of Light) of England, the Orloff of Russia, and the Tiffany of the United States.

The beauty of a cut diamond is due to the fact that the mineral has the highest index of refraction (see p. 268). Because of this fact, the light is internally reflected from facet to facet inside the gem, giving the appearance of a glow of light inside the jewel. (See Frontispiece.)

Another famous and valuable gem is the emerald, a mineral composed of aluminum, beryllium, silicon, and oxygen—a beryllium-aluminum-silicate. Its color is a deep green and a perfect emerald is more valuable than a diamond of equal weight. It has just been reported that emeralds have been made artificially and are so good that experts are deceived.

The ruby is much prized as a red gem, both it and the sapphire being corundum, an oxide of aluminum (Al_2O_3). It is now possible to produce rubies and sapphires in the laboratory but, because of the difficulty of manufacture, the cost is still high.

Quartz is an important gem-forming mineral. Although quartz (SiO_2) is a very common rock—pebbles being quartz—good gems are rather rare. Among the quartz gems are amethyst, chalcedony, carnelian, agate, onyx, sardonyx, jasper, and opal.

Opal deserves special consideration. The opal of gem quality has a marvelous mixture of colors. Perhaps the most valuable opals of the present time are the so-called black opals of Australia. Unfortunately, opals are rather fragile, which makes them unfit for hard usage.

Pearls, too, are gems of great value. This mineral is a hydrated calcium carbonate found in the shells of a certain mussel or pearl oyster. The method of formation seems to be as follows: A small

grain of sand or other impurity gets inside the shell. The mussel covers the irritating substance with layers of calcium carbonate. Thus a pearl is produced in a period of several years. In recent years, men have found it possible to place a seed in the shell of mollusks and to control the growth. Pearls are rather fragile, being attacked by acids. The luster of perfect pearls is unequalled by any other gem. Unfortunately, pearls deteriorate if left in dry deposit boxes and are harmed when worn on a dry skin.

ROCK CONSTITUENTS

It will be impossible in a text of this character to describe all of the minerals which exist in nature. Those to be described are of types which can be found in most localities, so that they are familiar to the average person. Fortunately, most of the common rocks are composed of only a few minerals and these will be described in detail.

CARBONATES. Among the carbonates which are well known are *calcium carbonate* (limestone, marble, and calcite crystals) and *magnesium carbonate* (dolomite). Although these minerals exist in a great variety of colors, it is a simple task to identify them by the acid test. Cold hydrochloric and other acids placed on calcium carbonate generate carbon dioxide, while hot hydrochloric acid attacks dolomite.

Another test for calcite in crystal form is the rhombic cleavage which occurs when it is broken into parts. *Calcite* (Iceland Spar) is a transparent crystal which resembles quartz upon casual inspection. It has, however, an entirely different crystal form.

Limestone is the common form of calcite. It is wide spread, consisting of the skeletons of marine animals (Fig. 68). These shells accumulate in layers at the bottom of ocean water and over a long period of years become rock. Due to impurities, limestones are found in many colors: gray, white, and blue. Because of the method of its formation, limestone is classed as a sedimentary rock. When limestones undergo great heat and pressure they change (metamorphose) into marble. Marble is classed as metamorphic rock. Other interesting limestone formations are the stalactites and stalagmites found in many caves (Fig. 69).

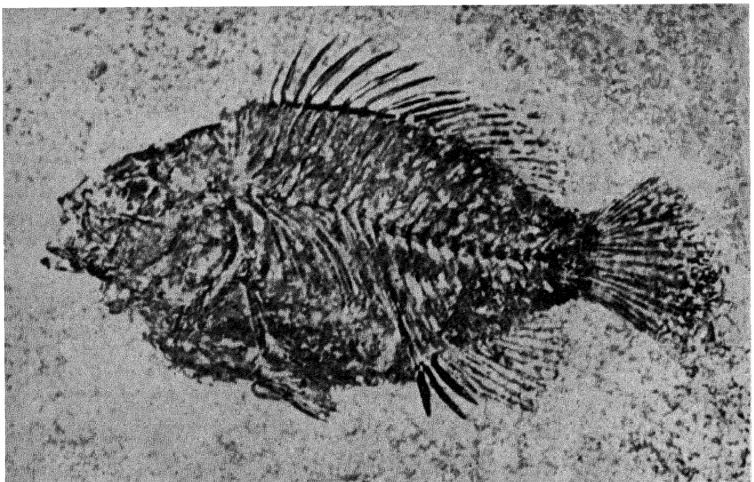

FIG. 68.—A fossil fish embedded in limestone.

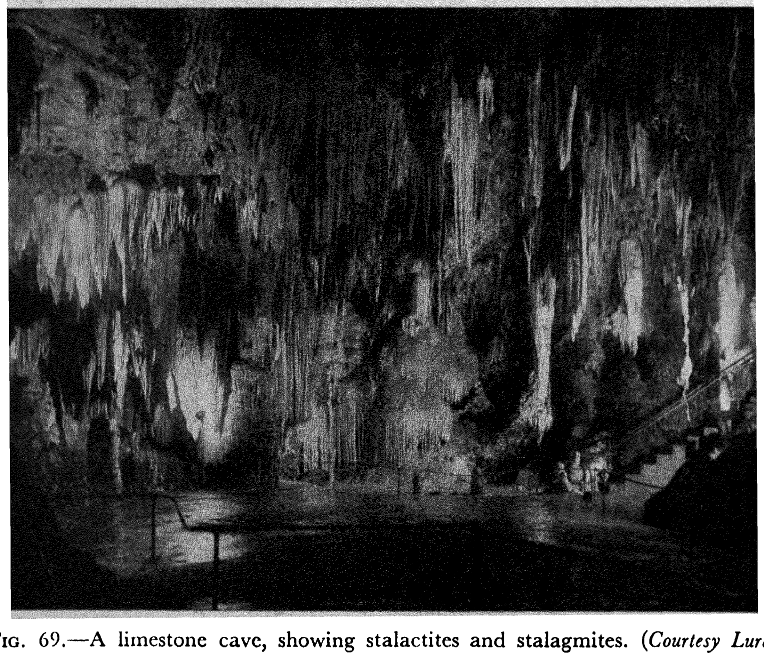

FIG. 69.—A limestone cave, showing stalactites and stalagmites. (*Courtesy Luray Caverns Corp.*)

SILICA AND SILICATES. Silica is usually called quartz (silicon dioxide, SiO_2). Quartz is a very common mineral existing in a great variety of shapes. There are crystals (Fig. 70) which have a characteristic pyramidal shape, and there are great masses of milky quartz. Some common varieties are rose quartz, smoky quartz, amethyst, and milky quartz. Some other varieties have already been mentioned in the discussion of gems. Quartz is a constituent of all granites and of many other igneous rocks. It can usually be recognized by its glassy appearance, although milky quartz is also a common ingredient of rock.

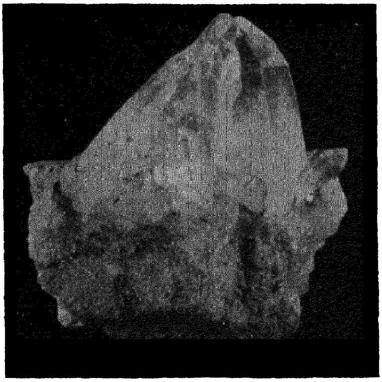

FIG. 70.—A quartz crystal.

When silica is combined with other minerals, we have the great class of silicates. The silicates which we shall have occasion to identify are the feldspars, the micas, hornblende, and serpentine. *Serpentine*, a rather common rock in Eastern United States and in Europe, is a magnesium silicate. Most varieties are green or yellow, and they are prized as building stone. Many buildings in the neighborhood of Easton and Philadelphia, Pennsylvania are constructed of serpentine. A prominent church in Cleveland, Ohio is built of the stone.

Feldspars are not always easy to identify by inspection. They resemble both quartz and calcite. Fortunately, simple tests distinguish them. Quartz is harder than the feldspars, and will scratch them. Feldspars are not as glassy as quartz and calcite. Most acids do not attack feldspars. A few of the common feldspars are orthoclase, microcline, oligoclase, and andesine. Although it is difficult to describe the varieties so that one can be distinguished from another, fortunately the amateur collector will not often need to make a distinction. In the field it is usually possible to identify the family of feldspars by scratching with a knife. This distinguishes them from quartz. The crystal form is the best

method of feldspar identification, but this is not practicable in the field.

One of the most interesting silicates is *mica*. This complex silicate, often called "isinglass," is best known in two forms; *muscovite*, which is transparent, or has a light color, and *biotite*, which is colored black or brown. Mica occurs in 6 sided crystals which cleave into sheets of almost microscopic thinness. Since it is very well known, it can readily be identified in rocks by its shining flakes. It is found in many types of rocks. Sheets of mica are used as insulators in electrical apparatus such as irons and toasters.

Hornblende is a black silicate having little luster. It is rather hard and is a constituent of many of the common igneous and metamorphic rocks.

SEDIMENTARY ROCKS

Sedimentary rocks are those which have been formed by the deposition of sediment either in water or on land. Rock fragments, pebbles, clay, and other minerals are piled up and pressed into layers forming rocks varying from a shale which crumbles in the fingers, to the hardest of breccias. Such rocks are divided according to their principal constituents.

CALCAREOUS ROCKS. Examples of this type are limestone, gypsum, and travertine. They consist principally of calcium carbonate. Limestone is a valuable building rock and is also crushed for use in road building.

SILICIOUS ROCKS. The outstanding example of this class is sandstone. This rock consists of small grains of quartz cemented together and colored with oxides of iron and other metals. Some varieties of sandstone are very hard and are much used as building stone. Other varieties can be worn away by the fingers. Broken down sandstone (sand) is used in the manufacture of concrete, glass, and carborundum.

If the quartz fragments are large and rounded, the rock is usually termed *conglomerate*. If the particles are sharp and angular, we term the material *breccia*.

Argillaceous. The most important members of this group are the clays and shales. As the igneous rocks weather, the quartz grains become sand and the feldspar and mica become clay and then shale. Although shales are usually soft, some varieties can be used as building stones. Blue shale is used in some of the buildings of Princeton University.

Carbonaceous. Most persons do not class coal and petroleum as rocks. However, both are composed of carbon minerals. Sedimentary coal exists in such forms as peat, lignite, and bituminous coal. *Peat* resembles plant fibers, and is found in ground where plants fell in water and did not completely decay. Good peat is brown in color and burns fairly well. It is abundant in Ireland and Minnesota.

Fig. 71.—A fossil leaf found in coal. (*Bowden.*)

As the peat bogs are subjected to great pressure and heat, a variety of coal called *lignite* is produced. It is better fuel than peat and is found in various parts of the world.

The most abundant form of coal is *bituminous*, a black, rather dirty fuel which burns with a good deal of smoke. It has a high fuel value (see p. 247) and is a standard coal in most parts of the world. England, Russia, and the United States produce the greater part of this fuel rock. Many tree fossils are found in coal beds, proving that coal is a result of tree decay (Fig. 71).

Petroleum. Petroleum is a liquid rock composed chiefly of paraffin and other hydrocarbons. Sometimes, as in the California petroleum, asphaltum is a constituent. Most persons are familiar with the crude petroleum, a sticky liquid from which we derive

such materials as kerosene, gasoline, petrolatum, tar, and many other liquids and gases (see p. 126).

Mineralogists are not in agreement as to the origin of petroleum. Did petroleum result from chemical energy in the earth or was it produced by the action of heat on the remains of animals and fish? It is known that heat can cause iron carbide to combine with water to form iron oxide and the hydrocarbons like petroleum. Since the core of the earth may be composed principally of iron, such an explanation is possible. On the other hand, petroleum may have been formed during the decay of organic matter in somewhat the same manner that coal was formed. Some support for this latter theory is given by the fact that oil deposits occur in salt domes which were formed under water in prehistoric ages.

IGNEOUS ROCKS

Igneous rocks were formed by the action of heat. Molten rock and lava from the lower part of the lithosphere were pushed upward and cooled. If the material cooled slowly, large crystals were formed; if it cooled rapidly, the rock became glassy in texture. It is evident that such rocks will contain no fossils. There will be no evidence of banding or stratification. An igneous rock has the same appearance from all sides.

One group of igneous rocks deserves only passing mention; the volcanic type consisting of obsidian and pumice. Such materials are not ordinarily found in regions where volcanoes are absent.

The other great group is called *plutonic*. These rocks were formed below the surface by the agency of great heat; were cooled under tremendous pressure, and are now found in the crystalline state. *Granite*, the best example of this group, makes a hard, durable building stone (Fig. 72). It is a coarse to fine-grained, light-colored rock. It is possible to recognize the feldspar, the quartz, and the mica by the shape of the grains.

In color, granite varies from light to dark gray and red. It is capable of high polish, and one may find beautiful polished

specimens of granite in many museums. Most granites contain quartz, mica, feldspar, and hornblende.

Syenite, another igneous rock, resembles granite. It differs, however, in that it does not contain quartz.

Diabase is quite similar to granite and makes an excellent monument material. However, the grains in diabase are microscopic in size, and it usually contains the iron ore, magnetite.

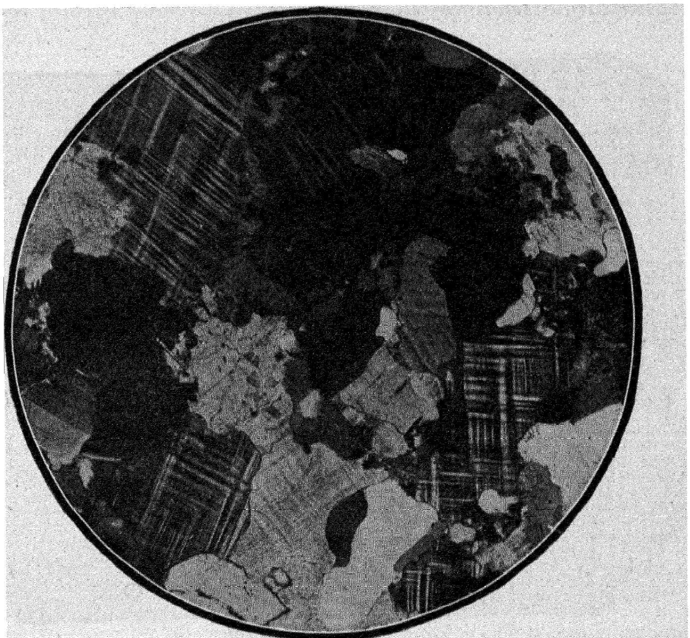

FIG. 72.—Photomicrograph of granite. Note crystals of quartz, feldspar, hornblende and mica. (*Courtesy of Ward's Natural Science Establishment, Inc.*)

Peridotite, the matrix for diamonds and other gems, contains mostly olivine and hornblende.

Basalt is the familiar dark, fine-grained, dense igneous rock, often called trap rock. It consists principally of hornblende. The Palisades of the Hudson are composed of basalt.

METAMORPHIC ROCKS

As the name indicates, these rocks have been subjected to heat, pressure, and perhaps other action in such a way that

they have been changed in structure. Because of the peculiar conditions which have produced metamorphic rocks, it is not surprising that they show banding and twisting. Both the igneous and sedimentary rocks have been changed in this way.

Granite becomes gneiss.

Diabase and basalt change to schist.

Limestone crystallizes into marble.

Sandstone becomes quartzite.

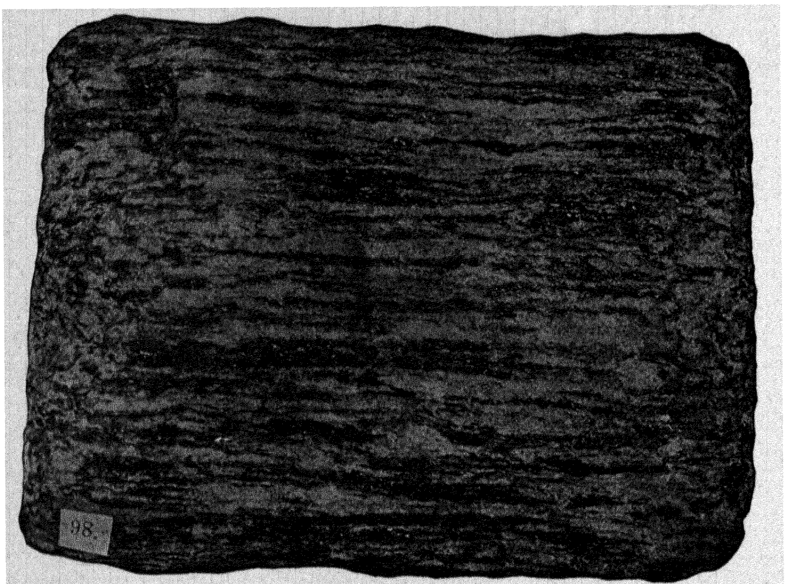

FIG. 73.—Biotite gneiss. (*Courtesy of Ward's Natural Science Establishment, Inc.*)

Shale hardens into slate.

Bituminous coal changes to anthracite.

Gneiss (Fig. 73), metamorphic granite, is a very common rock. It is hard, has a light color, and shows distinct banding.

It is easy to recognize when one is familiar with its characteristics.

If feldspar is absent from the gneiss-like rock, it is called *mica schist* (Fig. 74), composed principally of quartz and mica. Mica schist is often used as building stone. It does not weather readily,

and is very durable, although rather soft. Mica schist is a rock that every observer should know. In most cases the mica is so prominent and the banding so definite that identification is easy. Schists are named for the most prominent mineral, thus we have hornblende schist, talc schist, and chlorite schist. The schists often contain garnets.

A very interesting metamorphic rock is *quartzite*. It is very hard and durable, and does not cleave along a plane in the rock.

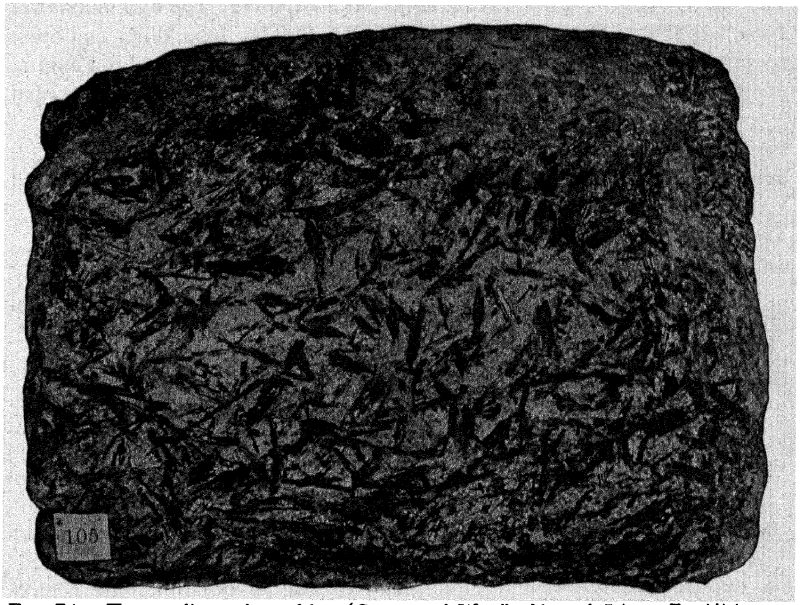

Fig. 74.—Tourmaline mica schist. (*Courtesy of Ward's Natural Science Establishment Inc.*)

It splinters, a fact that makes it difficult to shape into blocks. It is used to some extent in building.

Marble comes from limestone, as we have already emphasized. The best of marbles are very fine grained. Because of the grain structure, and on account of the beautiful white color, the marbles of Italy are unsurpassed in the world. Vermont and Georgia also produce much marble. Because marble is subject to chemical weathering, it has gone out of fashion as the stone used in monuments which are exposed to the weather.

It is believed that when bituminous coal was subjected to heat and pressure (usually by rock warping) the rock changed to *anthracite*. In this type of rock we have few fossils and the rock is nearly pure carbon. Anthracite coal is valuable because it burns slowly with intense heat and emits little smoke. It is probable that graphite and diamond are also metamorphic rocks.

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PROBLEMS

1. How do we know what kind of animals lived long ago?
2. How do we know that limestone is of animal origin?
3. The skeleton of a whale has been found in New York State near Lake Champlain. What does this indicate?
4. Explain why it is that metamorphic rock may at one time have been a sedimentary rock.
5. What is a gem?
6. What is an ore?
7. What is a mineral?
8. What is a rock?
9. Distinguish between sedimentary, metamorphic, and igneous rocks.
10. What are the different types of coal?
11. What is the origin of a pearl, a diamond, an emerald?
12. What is trap rock?
13. What is meant by the hardness of a rock?
14. What is fluorescence?
15. Distinguish between calcareous and argillaceous rock.
16. What is petroleum?

TOPICS

The history of famous diamonds.
Coal mining
Manufactured gems
A study of gems

LABORATORY EXPERIMENTS

1. Identify rocks in the laboratory
2. Collect and identify 10 rocks and minerals, labelling each.

Identification of Rocks

When identifying rocks, we make use of the properties of minerals described in the chapter. Many rocks weather extensively, hence it is necessary to study a freshly fractured surface whenever possible. This gives a clue to cleavage, fracture, and crystalline structure.

Try to determine from the general appearance whether a rock is of sedimentary, metamorphic, or igneous origin. Dip a glass rod into hydrochloric acid, and place the drop on the rock. Effervesence of carbon dioxide indicates limestone or marble. If dolomite is suspected, heat the acid slightly. Hard, dense, and heavy rocks are usually either ores or igneous rocks. Most rocks are either coarse or fine grained, which gives a clue to their identity. The next operation is to determine the exact mineral composition if possible. One must remember that rocks merge into one another, so that a specimen may have the characteristics of two types.

Coarse grained rocks may be sandstone, quartzite, granite, syenite, or diorite.

Fine grained rocks may be shale, slate, gneiss, schist, pumice, or basalt.

Before beginning a study of rocks it is necessary to learn the characteristics of the minerals hornblende, quartz, feldspar, mica, and calcite.

(*a*) *Hornblende*
  1. Hardness same as glass.
  2. Black or nearly so.
  3. Cleavage.
  4. Does not effervesce with acid.

(*b*) *Quartz*
  1. Scratches glass easily.
  2. Any color from colorless to black.
  3. Pyramidal crystals.
  4. Breaks like glass.
  5. No effervescence with acids.

(*c*) *Feldspar*
  1. Scratches glass, but is scratched by quartz.
  2. Usually light - white, gray, or pink.

3. Definite cleavage.
4. No effervescence with acids.

(*d*) *Mica*

1. Easily cut with a knife.
2. Colorless and yellow or brown or black.
3. Luster.
4. Cleaves into thin sheets.

(*e*) *Calcite*

1. Very easily scratched by needle.
2. Any color from white to black.
3. Crystal variety has cleavage.
4. Effervescence with acids.

SEDIMENTARY

(*a*) *Silicious* (Sandstone is an example)

1. Stratified; consolidated sand.
2. Fine, rounded, quartz grains or coarse angular particles.
3. Cemented together by *silica* (light colors—white, gray, tan, buff, or yellow); *carbonate* (gray); *iron-oxide* (red or chocolate brown); *clay* (gray).
4. Usually soft and friable.

(*b*) *Argillaceous* (Shale is an example)

1. Stratified; consolidated clay.
2. Very fine grained, flattened particles; often small mica flakes.
3. May grade into sandstone or limestone.
4. Black, blue, red, light gray.
5. Splits readily into thin leaves.

(*c*) *Calcareous* (Limestone is an example)

1. Compact. Can not see stratification.
2. Acids cause effervescence of gas.
3. Shell fragments sometimes seen.
4. Soft; scratched by a knife.

(*d*) *Carbonaceous* (Bituminous coal is an example)

1. Easily shattered along right angles.
2. Plant imprints sometimes seen.
3. Very soft.
4. Rich in carbon and its compounds.

IGNEOUS (Even texture in all directions)

(*a*) *Granite*

1. Coarse crystalline structure; minerals easily seen.
2. Color light gray; grayish green; red or pink.

3. Very hard; right angle cleavage.
4. Contains quartz, orthoclase, hornblende, and mica.

(*b*) *Syenite*

1. Coarse crystalline structure.
2. Resembles granite except for absence of quartz.
3. Pink, gray, or white.
4. Very hard.
5. Orthoclase, hornblende, augite, mica, but no quartz.

(*c*) *Diorite*

1. Medium to coarse glassy grains.
2. Dark gray or green.
3. Long prismatic needles good cleavage.
4. Plagioclase, hornblende or mica, or both.

(*d*) *Diabase*

1. Very fine grains, microscopic in size.
2. Dark color.
3. Augite, no quartz, may also contain hornblende and mica with magnetite.

(*e*) *Basalt*

1. Fine grained; dense and heavy.
2. Dark color nearly black.
3. Usually hornblende.

METAMORPHIC (Usually banded but not stratified)

(*a*) *Marble* (Metamorphic limestone)

1. Crystallized limestone.
2. Effervesces with acids.
3. White, mottled, or colored.
4. Soft, though harder than limestone.
5. Takes a polish.

(*b*) *Slate* (Metamorphic shale)

1. Cleavage planes.
2. Splits into sheets.
3. Very fine grained.

(*c*) *Anthracite* (Metamorphic bituminous coal)

1. Black and shiny.

(*d*) *Quartzite* (Metamorphic sandstone)

1. Quartz, with small amounts of impurities.
2. Usually light colored, but may be dark brown.
3. Splintery.

(*e*) *Gneiss*

1. Crystalline; rather fine minerals.
2. Banded.

3. Splits in one direction.
4. Hard.

(*f*) *Schist*

1 Crystalline, rather fine grained.
2 Some mineral usually prominent (See text under schist).

10

PRODUCTS OF ROCKS AND MINERALS

"It is only by overcoming Nature that man can rise."
Slosson

IN THIS chapter we pay particular homage to the chemists, those indefatigable workers who have torn things apart, fused, mixed, and constructed, thus giving us such a wonderful new environment.

Natural resources are of two general types those which are found within and as an integral part of the earth and those which, owing to the richness of the soil, grow upon it. The great industrial development of the United States, Canada, England, and a few other countries has been due largely to the wealth of mineral resources and to their development. China has great natural resources but they have not been developed extensively.

Our modern city environment is a manufactured one. Our houses are made of (or contain) concrete, brick, steel, glass, linoleum, asbestos shingles, plastic appliances, and paint, none of which are found, as such, in nature; we wear rayon clothes colored with synthetic dyes; we eat prepared breakfast foods; we enjoy artificially flavored and colored desserts; we walk on "composition" soles, use electricity, and read through glasses. We amuse ourselves by a host of manufactured radios, films, autos, and the like. Robinson Crusoe's was a purely natural environment- Dame Nature would scarcely recognize ours.

PETROLEUM

One of the great industries of the world is the refining of petroleum. The crude oil is pumped from wells into distillation tanks. In these tanks the petroleum is heated in such a way that the products are collected as gases at different temperatures.

Each product distills over at its own boiling point. This is called fractional distillation (Fig. 75).

The principal producers of petroleum are the United States, Venezuela, and Russia. Petroleum was first used in the United States as a medicine. The first oil well was drilled in Pennsylvania in 1860.

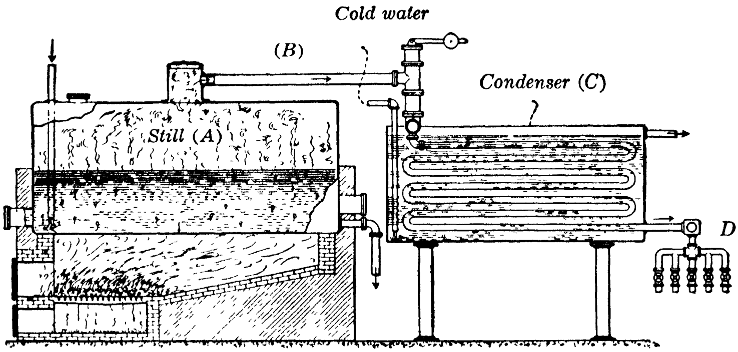

FIG 75 - Petroleum distillation. The crude oil is heated in still A. The vapors are condensed in C. The liquids are drawn off through D. (*From McPherson and Henderson's "An Elementary Study of Chemistry," Ginn and Co.*)

A large number of products are derived from petroleum, some of which are listed in the table below.

PARTIAL LIST OF PETROLEUM PRODUCTS

Gases	PROPANE	C_3H_8 Sold in tanks as fuel gas.	
	BUTANE	C_4H_{10} Fuel gas.	
	PENTANE	C_5H_{12} Solvent for rubber and varnish.	
	BENZINE	C_6H_{14} Dry Cleaning.	
Naphthas	GASOLINE	C_6H_{14} to C_9H_{20}	Fuel (see note).
	KEROSENE	$C_{10}H_{22}$ to $C_{12}H_{26}$	Fuel.
	GAS OIL	$C_{12}H_{26}$ to $C_{13}H_{28}$	Fuel for oil burners.
	HEAVY OIL	$C_{13}H_{28}$ to $C_{14}H_{30}$	Lubricating oil.
	PETROLATUM	$C_{14}H_{30}$ to $C_{15}H_{32}$	"Nujol" is an example.
Paraffins	VASELINE	$C_{16}H_{34}$ to $C_{20}H_{42}$	
	WAX	$C_{22}H_{46}$ to $C_{28}H_{58}$	"Parawax" and candles.
	TAR		Roofing.
Residuum	PETROLEUM COKE		Fuel, electrodes.

Note. *Gasoline* and other products listed above are *mixtures* of *hydrocarbons*, along with small amounts of other compounds. *Gasoline* contains *Hexane*

(C_6H_{14}), *Heptane*, *Octane*, and *Nonane* (C_9H_{20}). High test gasoline contains a larger proportion of the first two. *Ethyl gasoline* has had *tetra-ethyl-lead* added to reduce automobile knocking. The tetra-ethyl-lead reduces knocking by retarding the explosions in the cylinder. There are several other new compounds which show promise as anti-knock mixtures, notably isopropyl ether.

For many years after the discovery of petroleum, kerosene was the most valuable ingredient. With the coming of the automobile, the demand for gasoline became so great that the chemist was compelled to devise new methods to increase the yield. By "cracking" the heavy oils, the compounds can be broken down into lighter molecules for use as gasoline. This process is called destructive distillation.

HYDROGENATION. A process of hydrogenation has recently been perfected. High boiling point (heavy) oils contain a smaller percentage of hydrogen than light oils. By means of a catalyst, hydrogen at high temperature and pressure is caused to combine with the heavy oils, forming the more valuable light oils. The reaction takes place in a large nickel-chromium-steel chamber where the hydrogen and the petroleum are heated to 750°–1000°F. at a pressure of 3600 pounds per square inch. This pressure enables the refiners to produce larger yields of gasoline of very uniform characteristics. Much research has been done in this field within the past few years and the process gives promise of attaining great commercial importance. In addition to gasoline, hydrogenated solvents for the paint, varnish, lacquer, and textile industries are being developed, as well as a safety fuel for boats and aircraft. Gasoline is also being manufactured by the hydrogenation of coal.

CATALYSTS

A catalyst is anything that aids or retards a chemical reaction, without being permanently changed or becoming a part of the final products. Finely divided nickel, when added to a mixture of hydrocarbons and hydrogen, aids the reaction between them. The nickel is removed later by filtering. Hydrogen combines with hydrocarbons when under very high temperature and pressure, but nickel causes the reaction to take place at a much lower

temperature and pressure. Another example of catalytic hydrogenation is the manufacture of hydrogenated fats from cottonseed oil (see p. 374). Zinc oxide catalyzes the reaction between hydrogen and carbon monoxide to form methyl alcohol; platinum may be used as a catalyst in the manufacture of sulfuric acid and ammonia; iron oxide may also be used in making sulfuric acid; copper is used in the formation of certain dyes. These are examples of catalysts which aid a reaction. Anti-oxidants used in automobile tire rubber are examples of retarding catalysts.

COAL PRODUCTS

Bituminous coal is another interesting resource from which we derive an astonishing array of products. There are three general groups of coal products: coal gas, tar, and coke. These are produced by heating coal in large retorts without access to air (destructive distillation). The type of furnace and the character of the product varies, as they depend upon the purpose of the operation. Some companies make fuel gas to supply the heat and light requirements of a community. In this case the equipment and its operation are designed to produce a maximum gas yield; coke being but a by-product, and the tar being wasted. Other companies make coke; using the gas to operate their furnaces. One-seventh of all coal mined in the United States is used to supply coke for metallurgical uses. In many instances the coal tar and ammonia are lost.

Since 1914 there has been such a great demand for coke, ammonia, and coal tar that many by-product coke ovens have been constructed. Some of the coal gas which is formed in these ovens is used in their operation, but much of it is sold as fuel gas. A ton of soft coal yields about 12,000 cubic feet of gas. The coal tar which is driven from the coal is washed; as much as 25 pounds of ammonium sulfate per ton of coal being reclaimed from the washings. (Ammonium sulfate supplies ammonia for explosives, fertilizers, and other nitrogenous compounds.) About 125 pounds of tar remain, from which are prepared the many substances shown in Fig. 76.

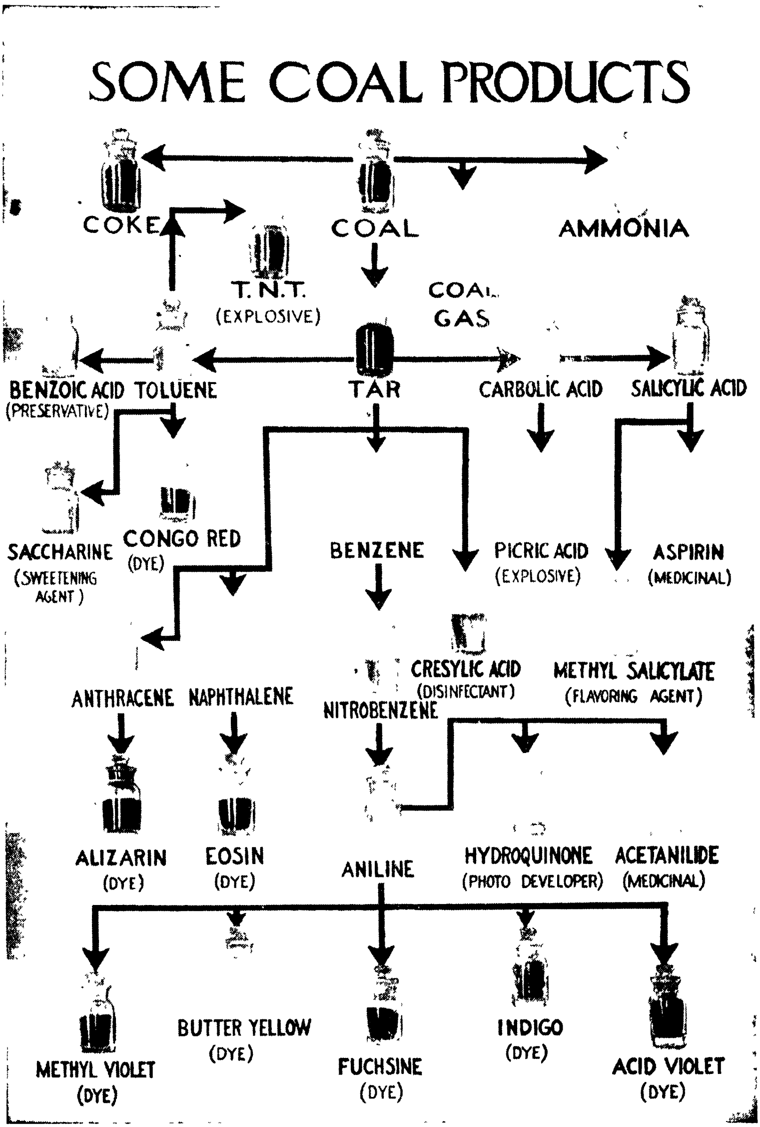

FIG. 76.—Some products derived from coal. (*From McPhersons and Henderson's "General Chemistry," Ginn and Co.*)

Here we have another example of a miracle of chemistry. Years ago the black, messy, sticky, ill-smelling tar was an expensive nuisance. A young man named Perkin, in 1856, spent his Easter vacation puttering around a laboratory with some of this tar. To his surprise he made a beautiful mauve dye. This discovery opened the door to the development of modern coal tar products, such as explosives, antiseptics, dyes, perfumes, aspirin,

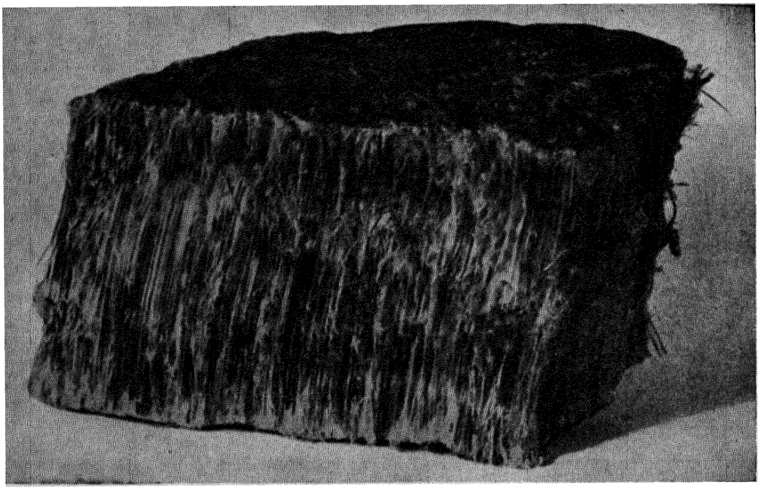

FIG. 77.—Asbestos—note fibrous appearance. (*Courtesy of the Mines Branch, Ottawa, Canada.*)

photographic materials, carbolic acid, and roofing tar. This subject will be discussed more fully in Chapter 22.

A ton of coal also yields about 1200 to 1500 pounds of coke. Coke is used in a variety of ways. Some is burned as household fuel. Most of it is used for industrial purposes, such as the reduction of metals from their ores, the synthesis of methyl alcohol and of acetylene, and the manufacture of carborundum and graphite.

ASBESTOS

Some forms of this rock closely resemble textile fibers in gross appearance, as can be seen in Fig. 77. It occurs in compact bundles of long, slender, flexible, silky looking fibrous masses. *Chrysolite* (a form of serpentine), *tremolite*, and *actinolite* are three

minerals whose crystals may form in such a manner as to be termed asbestos. *Asbestos* has many uses due to its flexibility, its fire resistance, and its electrical insulation properties. The short crystals are mixed with other material forming such things as wallboard and heater pipe insulation. The long fibers are used in the manufacture of asbestos curtains, fire suits, and similar things.

CEMENT

The Romans made cement but the knowledge seems to have died with them. It is only since 1900 that cement has again become popular. It is made by pulverizing and heating a mixture of limestone and clay or shale in rotary kilns. A mixture of blast furnace slag and lime may also be used. The partly fused clinker mass is again pulverized and sold as cement. It is made into concrete by mixing cement, sand, crushed rock, and water. Concrete is a man-made rock which surpasses natural rock in durability and ease of handling.

GLASS

The art of making glass is very old, being well known in Egypt in 1400 B.C. At present there are several types of glass such as window glass, bottle glass, cut glass, and pyrex. The general method of manufacture is to heat a mixture of sand (SiO_2), limestone ($CaCO_3$), and sodium carbonate (Na_2CO_3), or sodium sulfate (Na_2SO_4) until they fuse. The molten mass is then blown into molds. (Fig. 78.) Window glass is blown into long cylinders which are cut length-wise while still hot and allowed to flatten into sheets. Plate glass is rolled into sheets on a hot steel table. Various substances may be added during the fusion process to produce special types of glass. *Pyrex* contains boron oxide (B_2O_3). This glass is interesting because of its toughness and its low coefficient of expansion. In fact, a pyrex dish may be placed over the open flame without danger. Ordinary glass which is used in window panes is called *soda glass*. The glass used for *cut glass* contains lead oxide (PbO). Such a glass is brilliant but is not suited for many purposes because of its softness.

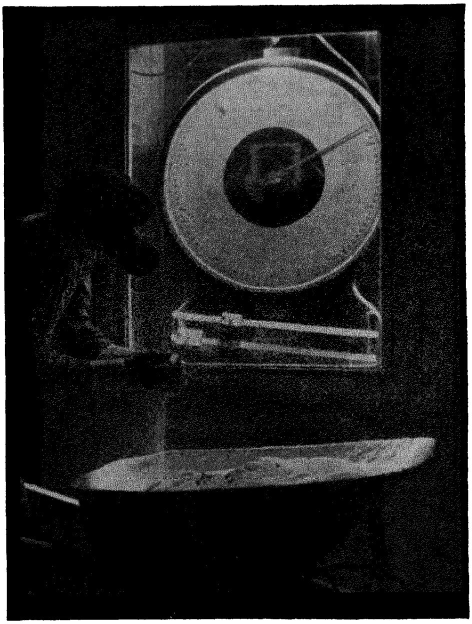

FIG. 78(a).—Weighing the mixture. (*Courtesy Pittsburgh Plate Glass Co.*)

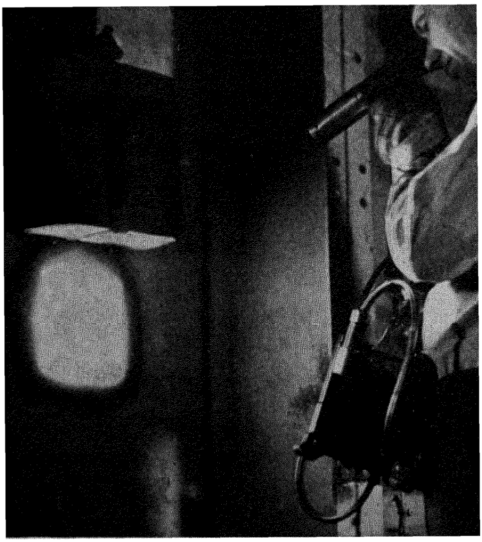

FIG. 78(b).—Measuring the furnace temperature with an optical pyrometer. (*Courtesy Pittsburgh Plate Glass Co.*)

The coloring of glass is a very interesting process. In order to produce colored glass various chemicals are added, principally metals. These metals are mixed in the glass in a *colloidal* form. For example, both gold and selenium produce a red glass, but the gold one is much more attractive. Chromium compounds color glass green, and iron compounds make amber glass.

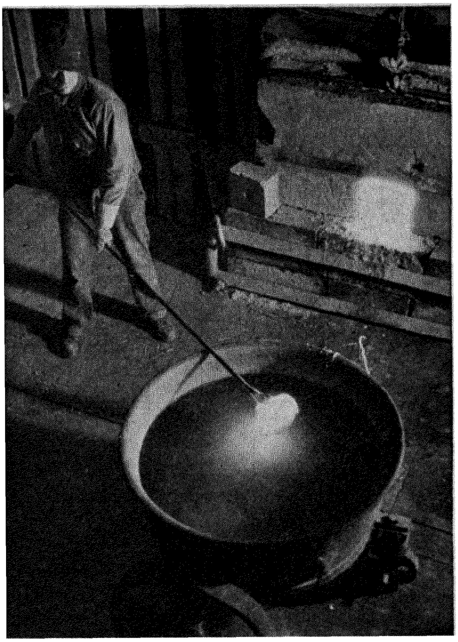

FIG. 78(c).—Taking a sample of the melt. (*Courtesy Pittsburgh Plate Glass Co.*)

Most glass transmits all light except the ultra-violet, which it absorbs. Ultra-violet is useful in the prevention of rickets, hence it is desirable to have a glass which will transmit these rays. Considerable research is being carried on with the aim of providing a cheap glass for hospitals, homes, and nurseries. Glass made from fused quartz will do this but it is too expensive for common use. Examples of "ultra-violet glass" are "Corex," "Vita Glass," and "Cobalt-Nickel Glass."

Safety glass is made by cementing a sheet of cellophane between two sheets of ordinary glass. Bullet proof glass consists

of several layers cemented together. Such glass will crack but will not shatter. A better type of safety glass is still needed, one that is transparent, flexible and yet rigid enough for ordinary pressures. There is hope that such a material will be produced from the plastic industry (see p. 431).

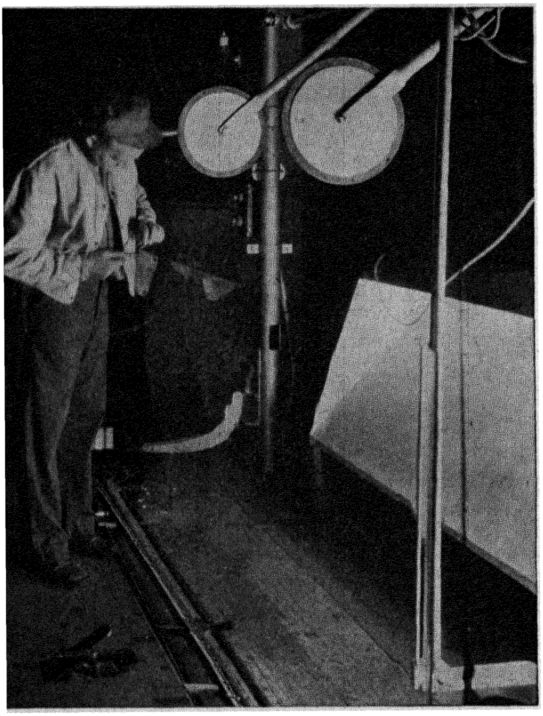

FIG. 78(d).—Testing the glass for uniformity. (*Courtesy Pittsburgh Plate Glass Co.*)

METALS AND ALLOYS

No metals are found free in nature except gold, lead, platinum, copper, and silver. For the most part, metals are combined with other elements, being found as carbonates, sulfides, silicates, and oxides. Such rocks are called *ores*. Iron ore, for example, is a rock which contains large quantities of some compound of iron. Indeed some ores are nearly pure metallic compounds, for instance, the iron ore, hematite, in northern

Minnesota. Others contain rather minute quantities of metal, as in 3.88 tons of pitchblende there is only one gram of radium (see p. 210).

There is a large number of ores. The manner of securing the metal from the ore depends upon its concentration in the rock, its chemical composition, and its chemical conduct. In general, the ore is crushed and roasted. Coke is added to remove oxygen from the metal and some material is used to purify the crude metal. The molten metal is then drawn off and worked into the desired form. Sometimes electrolysis is used to purify the metal. Commercial copper is treated in this manner. The methods of extracting metals from their ores constitute the subject of metallurgy. Such methods are treated in the chemistry texts and will not be explained here.

Pure metals have a rather limited use, most of the metallic substances of industry being alloys. However, mercury is used rather widely in the pure form and so are platinum, copper, and lead. Most metals are either too soft or too active chemically to be very practical. Gold, silver, and aluminum are too soft for most purposes. Ordinary iron is too soft and rusts too readily. However, in recent years, a type of iron called "Armco" has been developed which is quite resistant, so that it can be used for exposed work.

ALLOYS

Alloys are man-made metals. New alloys are being developed at a rapid rate to meet the ever increasing needs of mankind. Only a few years ago, the breaking of an automobile spring was a common occurrence. Today we rarely break a spring. This is due to the improved alloys that are used. The modern spring does not weaken under the constant vibration which it experiences. In aviation, we need light but strong engine and body metals. No pure metal meets the needs of the airplane. Iron is neither light nor strong enough, aluminum is light but too flexible. By adding some magnesium, copper, and manganese to aluminum we produce duralumin which is ideal for airplane use (Fig. 79). Again there are no metals strong and hard enough to drill and machine certain alloys. Metallurgists are now producing alloys

which maintain a sharp edge. Such an alloy is cobalt-tungsten. This material is so hard that it will cut sapphires and get still harder while it is being used. By its means we can cut glass about as easily as a steel tool cuts brass.

Still another type of alloy is very resistant to corrosion. If chromium, nickel, or copper are added to iron or steel we have the *stainless steels.* Such products can be laid under salt water

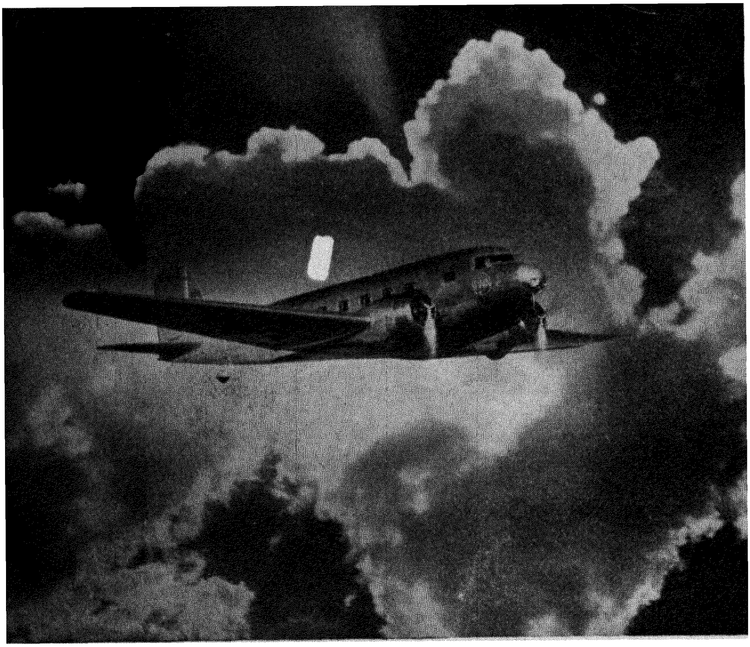

FIG. 79.—This modern airliner is made of aluminum alloys.

indefinitely without corrosion. Stainless steels are used for outdoor construction, cutlery, and sheathing. The new light-weight trains built by Budd Manufacturing Company are constructed of welded stainless steel. The Empire State Building has a stainless steel dome which will probably last as long as the building stands. In the manufacture of electric lamp filaments, the metal tungsten is alloyed with thorium. This makes it possible to draw the wire into very fine wires.

An alloy is the result of melting two or more metals together (a few non-metallic elements such as sulfur, carbon, phosphorus, and silicon are used in some alloys). The word *alloy means* to *bind*. Alloys have been known for centuries, but it is only recently that they have been extensively developed. Copper was probably the first metal which was alloyed. Pliny mentions the substance, bronze, which was an alloy of copper and tin. In fact, we speak of the Bronze Age, a period in the history of civilization. However the only metals alloyed up to the eighth century were copper, tin, zinc, gold, silver, and mercury. A few examples of early iron remain, one a sword blade taken from the tomb of Tutankhamen.

Some alloys are chemical compounds, while others are mere mechanical mixtures. Alloys often have strangely different properties from the parent elements. An outstanding example is Wood's Metal which melts in boiling water, a much lower temperature than the melting points of any of the constituents. Because of its low melting point this alloy is used as a plug for fire sprinklers. There are hundreds of alloys, but most of them can be included in a simple classification shown by the following list. *It must be emphasized that the list contains only a few of the many alloys.*

I. *Iron.* The many alloys of iron are called steel.
   (*a*) CHROMIUM STEEL.
      1. *Stainless steel* is 14% chromium.
      2. *Armor plate* contains some nickel.
      3. *Stellite*, a very hard alloy, contains cobalt and tungsten.
      4. Acid proof pipes, valves, sheathing contain chromium.
   (*b*) TUNGSTEN STEELS are very hard and are made into tools.
   (*c*) NICKEL AND COBALT steels are magnetic.
   (*d*) NITRALLOY is the name given to the alloy formed by a new process in which the surface of steel is coated with iron nitride by exposing to ammonia fumes at a high temperature. The surface is one of the hardest materials known.

II. *Copper*
   (*a*) BRASS is made from copper and zinc.
   (*b*) BRONZE is an alloy of copper and tin.

III. *Aluminum*
   Aluminum alloys are being developed for airplanes, trolley cars, trains, and autos. They are strong and light.

(*a*) DURALUMIN contains 95% aluminum, 3.7% copper and a little magnesium.
(*b*) BERYLLIUM-aluminum alloys are lighter and stronger than aluminum.
(*c*) DOW METAL, which is 85% magnesium, is the lightest useful metal known. Being strong, it is used for trucks and stratosphere gondolas. A large covered truck of Dow Metal weighs less than a small open truck of steel.

IV. *Mercury alloys* are termed amalgams. They are used in dental fillings.

V. *Nickel alloys* are silver colored.
(*a*) GERMAN SILVER contains nickel, copper, and zinc but no silver.
(*b*) PERMALLOY contains 78% nickel and 21% iron. It has excellent magnetic properties and has made possible high speed cablegrams and the hand telephone.
(*c*) MONEL metal is about 70% nickel, 28% copper and 2% iron. It is used for sinks, soda fountains, and in all interior and exterior finishings. It rivals stainless steel in its durability.
(*d*) NICKEL coins are a mixture of nickel and copper.
(*e*) The new metal ALNICO forms such a strong permanent magnet that it is used in the newest radio equipment, making possible a much simpler construction for dynamic speakers.

VI. *Pure gold* is said to be of 24 carat quality. This is too soft for most purposes and it is usually alloyed either with copper or silver.
(*a*) United States coins contain 90% gold and 10% copper.
(*b*) British sterling is 91.67% gold and 8.33% copper. (Sterling silver contains 92% silver and 8% copper.)

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PROBLEMS

1. Explain these terms: distillation, destructive distillation, fractional distillation, hydrogenation.

2. Is there any danger of a shortage of gasoline within the next fifty years or so? Why?
3. Why is an asbestos curtain required in theaters? Discuss the possibilities of a substitute for asbestos.
4. List all the uses of cement which you know.
5. What advantage does pyrex have over other types of glass?
6. Why has it become necessary to develop new alloys?
7. Why are none of the pure metals suitable for airplane construction? Auto frames?
8. Why is steel output used as a barometer of business conditions?
9. What is Dow Metal?

TOPICS

Ceramic Products.	Stainless Steel.	Alnico.
Metallurgy of Various Ores.	Permalloy.	Refining.

Report on any coke plant in your vicinity. Is the tar used or wasted?

VISUAL AIDS

Exhibits of alloys, aluminum, copper, ceramics, and coal tar products are helpful and may be secured from sources noted in the appendix. Motion pictures: "BITUMINOUS COAL," "IRON TO PIG IRON," "PIG IRON TO STEEL." Eastman Classroom Films.

EXPERIMENTS

1. Construct apparatus as shown in Fig. 80. Half fill the tube *A* with crushed bituminous coal. Clamp it in a horizontal position; tap gently to form a pathway for the escape of gas along the top of the coal. Connect the tube to the rest of the apparatus. Heat the coal vigorously. Ignite the fumes escaping from the jet. Continue heating until fumes cease to come from the coal. Examine coke and tar.

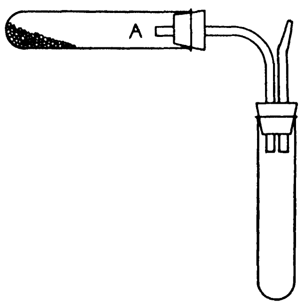


FIG. 80.—Destructive distillation of coal.

2. Heat a small amount of cinnabar in a pyrex tube. Very cautiously sniff the gas evolved. Describe the residue in the tube. What is it?

3. Mix 2 parts of sand and 1 part of cement. Mix in enough water to make a doughy mass. Pour this into a candy box (to make a concrete brick) or cement some stones together. Let it set for 24 hours and examine.

4. Make an alloy such as Wood's Metal which has a low melting point.

5. Purchase a horseshoe magnet made of "Alnico" and study its properties.

II

THE ATMOSPHERE

> "*Which is as thin of substance as the air*
> *And more inconstant than the wind.*"
>
> *Shakespeare*

FOR AGES men have known that they lived at the bottom of a great ocean of some mysterious substance. They experienced the effects of great storms and heard the roaring of the winds. In their superstition they attributed these effects to the wrath of angry gods and to the moaning of lost souls. Today we know that these effects are caused by the atmosphere of gases around us which we term the *air*.

The atmosphere of a heavenly body is the gaseous envelope around it; on Jupiter the atmosphere is composed of *methane* and *ammonia;* on the earth the atmosphere is principally *oxygen* and *nitrogen*. The air is a mixture of various gases. These gases are not combined in a chemical way, they do not bear a definite proportion to each other and the constituents can be separated by physical methods. Nevertheless, at the surface of the earth, most of the gases bear a rather definite relation to each other.

The gases present in the lower atmosphere include:

Nitrogen	78 03%	Hydrogen	01%
Oxygen	20 99%	Argon	94%
Carbon Dioxide	03% (Approx.)	Neon	0018%
Water vapor		Helium	0005%
Xenon	000009%	Krypton	0001%

Because of the earth's atmosphere we have a comparatively uniform temperature. The radiation from the sun is intercepted so that the earth becomes neither excessively hot at midday nor too cold at night, as it would if there were no atmosphere. (As has been mentioned on page 44 the lack of atmosphere on the moon causes great extremes of temperature there.) At night the air acts as a blanket that retains the heat of the earth. Clouds also

blanket the earth preventing severe extremes of temperature. Few of us realize the extent to which the air protects us. Even in the polar regions the temperature never falls more than 100 degrees below freezing. The atmosphere is like a green house in that it permits the energy of light and heat to enter but prevents the escape of the heat energy from the ground. Much of this protection is due to the water vapor and carbon dioxide. Our atmosphere scatters the sunlight giving us daylight. It also makes possible the transmission of sound waves.

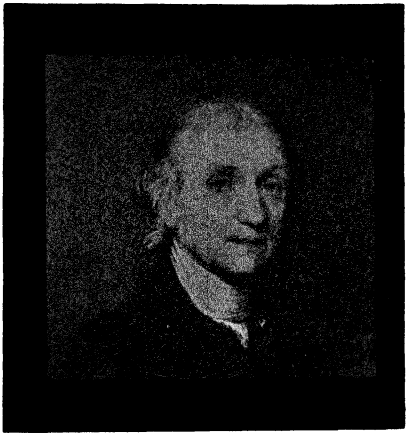


Fig. 81.—Joseph Priestley (1733–1804). English clergyman, schoolteacher and scientist; discovered a number of gases, including oxygen, nitrous and nitric oxides, sulfur dioxide and hydrogen chloride; settled in Northumberland, Pennsylvania in 1794, where there is now a memorial to him. (*Hackh.*)

Oxygen, nitrogen, carbon dioxide, and water vapor are all essential for life on the earth. It seems that the proportions of these gases have remained about the same for long geological periods. As has been stated in Chapter 8, it may be that during the coal forming periods there was an excessive amount of carbon dioxide in the air and, that during the glacial ages there was less than at present. However, we have no direct evidence for this theory. All animals and plants (except a certain few which are anerobes) use atmospheric oxygen and eliminate carbon dioxide. All plants which contain chlorophyll (see p. 385) use

carbon dioxide and eliminate oxygen. In this way the balance of the oxygen and carbon dioxide in the atmosphere is kept constant.

Oxygen was first made by Priestley (Fig. 81) in 1774. He heated some mercuric oxide (HgO) and found that the gas given off caused substances to burn vigorously. Even red hot iron burned in the gas. Lavoisier (Fig. 82) also studied the new gas giving it the name *oxygen*.

FIG. 82.—Antoine Lavoisier (1743–1794). Named oxygen and other chemical substances, introduced quantitative chemistry. Has been called the "Father of Nutrition." (*Brownlee, Fuller and Hancock "Elementary Chemistry," Allyn and Bacon.*)

One of the functions of nitrogen in the air is the dilution of oxygen. Were the air pure oxygen, fires would be uncontrollable and metals would oxidize very rapidly. On the other hand, life would be still possible because of the fact that we can breathe pure oxygen. The lungs absorb only the amount needed and reject the balance. (Because of this, oxygen is used for persons ill with pneumonia and for mountain climbers.) In the atmosphere nitrogen is rather inert. However, when combined with oxygen or hydrogen it forms a great number of important materials. By causing nitrogen and hydrogen to combine in the presence of a catalyst (see p. 127), ammonia gas is produced. The chemist can use ammonia in the production of nitrates both for fertilizer and for explosives. It is interesting that, although nitrogen is not active in the air, yet in combination with other elements it is an important constituent of such active substances as explosives and protein foods.

LIQUID AIR

Although oxygen and nitrogen exist as a mixture it is difficult to separate them. Perhaps the best method is that of liquefaction and subsequent distillation. Air when highly *compressed* and *cooled* becomes a liquid. One of the amazing feats of science was the

development of methods of producing liquid air. Although a complete explanation of the principles of the production of liquid air is outside the scope of the text, we shall give a brief description of the apparatus. Figure 83 illustrates the process schematically. D and B are the compressors. C and E are coolers. The liquid air forms in the liquifier F. Liquid air has very interesting properties. Since its temperature is extremely low, mercury can be frozen

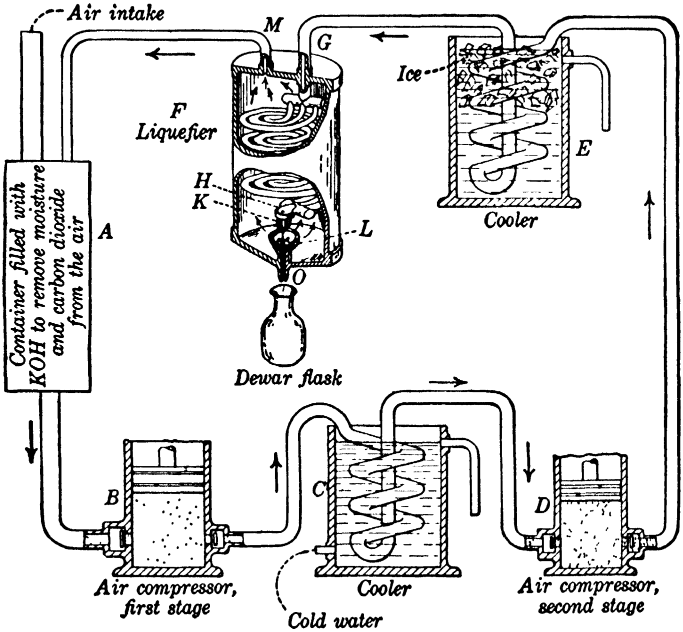


FIG. 83.—Schematic diagram of the process of manufacturing liquid air. (*McPherson and Henderson "General Chemistry," Ginn and Co.*)

when placed in the liquid. Rubber becomes a brittle solid, so that a frozen rubber ball will break if bounced on the floor. Lead becomes so elastic that a bell of the metal at liquid air temperatures has a tone like one of silver. Liquid air is used in many commercial operations which involve low temperatures. If the liquid is poured on a cake of ice, it will boil like water on a red hot stove (Fig. 84).

If liquid air is carefully heated, the gases can be separated. Nitrogen boils off first at $-195.8°C$. The oxygen follows at a

temperature of $-182.5°C$. Each of the inert gases can be isolated by carefully controlling the temperature. By this means all the gases can be produced cheaply. It costs but a few cents to produce

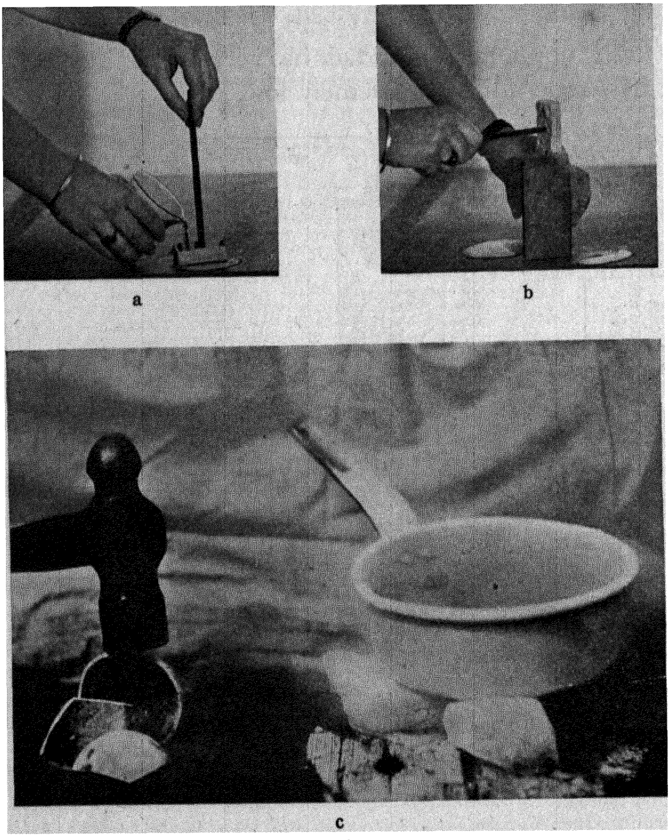


FIG. 84.—Experiments with liquid air. (a) Pouring mercury into a paper mold to be frozen. (b) A hammer made of mercury being used to drive a nail. (c) A rubber ball frozen in liquid air breaks under the blow of a hammer. The pan of liquid air is boiling on a cake of ice. (*Courtesy Air Reduction Sales Company.*)

the rare gas, argon. Even the rarest gas, xenon, can be produced at moderate cost.

For a long time the inert gases had no commercial use. Today, argon is used in the manufacture of all electric light bulbs. By filling the bulb with the gas the evaporation of the tungsten

filament is retarded, which lengthens the life of the bulb (see p. 262). Everyone is familiar with the red glowing signs containing the gas, neon. By mixing argon, helium, and mercury vapor, various colors are produced in advertising signs. Up to the present, krypton and xenon have been laboratory curiosities but, it is now predicted that they, too, will be utilized in a new lamp for home use.

THE NATURE OF GASES

We recognize at least three states of matter – *gas*, *liquid* and *solid*. For example, the forms of water are ice, liquid water, and the gas called water vapor.

A gas is composed of atoms or molecules which are quite distant from each other. These particles are in rapid motion, traveling at speeds of the order of several miles per minute. They are believed to be constantly colliding and flying apart, moving in various directions. The higher the temperature the greater their kinetic energies, so that the molecules tend to separate further (expand). When gases are heated they expand and when they are cooled they contract. This is the principal cause of weather.

Inasmuch as molecules are invisible, indirect methods must be used in the determination of molecular speeds. Most of our methods for the study of gases are based on the results of the work of Boyle and Charles. These early investigators studied the properties of gases and summarized their results in two laws which are named after them. Boyle's law states that, *if we increase the pressure on a certain volume of gas, we make the volume smaller.** For example, a cubic foot of air at atmospheric pressure (14.7 pounds per square inch) would have a volume of only ½ cubic foot if the pressure were doubled (29.4 pounds per square inch). Charles' law states that *all of the common gases undergo a change in volume of 1/273 of their volume at 0°C., when the temperature is raised 1°C.** This law means that if we heat 100 cubic centimeters of air

* In Boyle's Law we are careful to keep the temperature constant. In Charles' Law the pressure must remain constant.

from 0°C. to 20°C., keeping the pressure the same, the new volume will be $100 + \frac{100 \times 20}{273}$ which is 107.3 cubic centimeters.

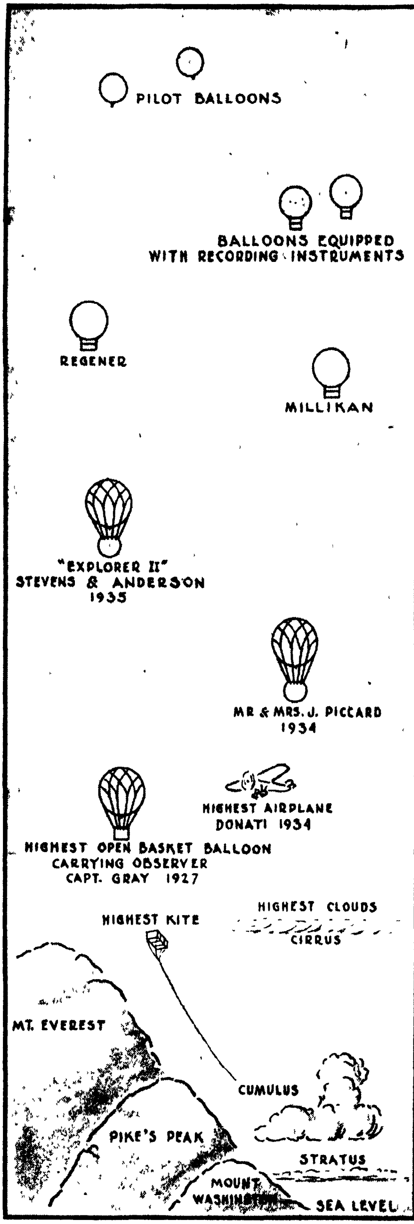
By studying the changes of volume with pressure and temperature, we arrive at the conclusion that a space such as the room is filled with molecular "bullets" moving at high speeds, colliding with each other and rebounding from the walls. The lightest gases, for example hydrogen, seem to have the highest speeds at any given temperature. Because of the gravitational effect of the earth, the heavy, slow moving molecules are held close to the surface of the earth, while the lighter gases escape. It is believed that all of the gases on the moon have escaped during past ages because of the small force of gravity on the moon.

Because we are unable to see air, we fail to realize that it is made up of any material substance. However, when a strong wind is blowing and we are obliged to push ourselves against it, we realize that even though we cannot see it we are being pushed by the air. A wind of tornado velocity can wreck strong buildings. If we could insert a little window in the side of a tire which is supporting a heavy truck, we would be unable to see anything inside the tire. But if we puncture the tire, we hear the escaping gas and the tire flattens. Thus we realize that the air is supporting the weight. The millions of air particles are constantly bombarding the inside of the tire, causing the pressure.

As a person climbs to an altitude of several thousand feet he notices a difficulty in breathing because of the thin air. It is necessary for him to breathe in more of the air to secure sufficient oxygen. At very high altitudes—above three miles—tanks of oxygen must be carried. It is estimated that the air extends to a height of about 300 miles. Nevertheless, one-half of the air by weight lies below the three mile level. Aviators have flown 8 miles high by using oxygen.

In 1935, Stevens and Anderson, using a stratosphere balloon reached a height of 13.7 miles.* At this height only about 4% of the atmosphere remained. The aviators were sealed in a

* It is of interest to remark that at this elevation the aviators were able to see that the surface of the earth was curved.



HEIGHT		BAROMETER		TEMP.	OBSERVATIONS
MILES	KM.	INCHES	CM	CENT.°	
25.0	40.2	0.08	0.2	-60.0 ?	POTENTIAL 400,000 VOLTS ABOVE EARTH
					TEMPERATURES ESTIMATED
20.0	32.2	0.27	0.7	-60.0 ?	
15.0	24.1	0.90	2.4	-60.0	
13.7	22.1	1.18	3.0	-59.0	HIGHEST POINT REACHED BY MAN. 96% OF ALL THE ATMOSPHERE BELOW THIS LEVEL
10.0	16.1	3.20	8.1	-58.0	
					APPROXIMATE BASE OF STRATOSPHERE AND TOP OF TROPOSPHERE. NO MOISTURE, NO DUST, NOR CLOUDS ABOVE THIS LEVEL
5.0	8.1	10.60	27.0	-38.0	
3.5	5.6	15.00	38.0	-21.0	HALF OF ALL THE ATMOSPHERE BELOW THIS LEVEL
0.0	0.0	30.00	76.0	0.0	

FIG. 85.—Information about the atmosphere. (*Foley.*)

spherical ball and breathed oxygen from liquid air. They found that at this elevation the stars were shining in the daytime because there was no atmosphere to scatter the light.

Some of the interesting facts about the atmosphere are shown in Fig. 85. The atmosphere is divided into the troposphere (weather layer) and the stratosphere. As can be seen from the figure, water vapor is not found above the ten mile level. Above 70 or 80 miles the atmosphere probably consists mainly of hydrogen and helium.* Some information on this point can be gained by studying meteor flight and by an investigation of the spectrum of the aurora borealis.

WEIGHT AND PRESSURE OF THE AIR

Air is a substance which occupies space and has a definite weight. One liter (about one quart) of clean, dry air weighs 1.293 grams at 0°C. (32°F.), and 760 millimeters pressure. This is equivalent to about one ounce per cubic foot. The air in an average room weighs more than one hundred pounds. We can see that, because the air has weight, the entire blanket of air which covers the surface of the earth must be exerting an enormous force upon the surface.

A new fluffy pillow is very light in weight. When one hundred such pillows are piled on top of each other, the total weight will be considerable. The feathers in the top pillow will not be pressed together while those in the bottom pillow will be very compact. In the same way, the molecules of gas making up our air are widely scattered at high altitudes, but the lower molecules are compressed. The air exerts a pressure of 14.7 *pounds per square inch* at sea level. A man of ordinary size has a force on his body of about 14 tons but, because of the air inside of his body, he is not aware of this great force unless he ascends rapidly. Airplane travelers are advised to swallow while the plane is rising. This equalizes the pressure in the middle ear.

We utilize the pressure of the atmosphere in many common operations of daily life. We "suck" liquids through a straw

* In 1918, a shell from a "Big Bertha" rose to a height of 20 miles on its flight to Paris, 75 miles away.

by creating a vacuum in the tube. The atmosphere then forces the liquid up into the mouth through the tube. In the ordinary lift pump (Fig. 86) the upward motion of the piston creates a

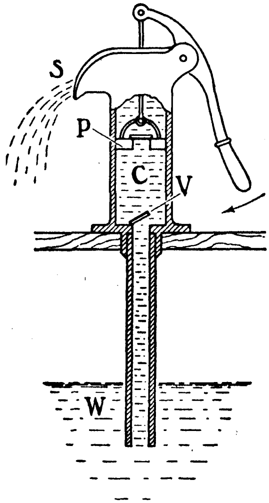


FIG. 86.—The lift pump. (*Foley.*)

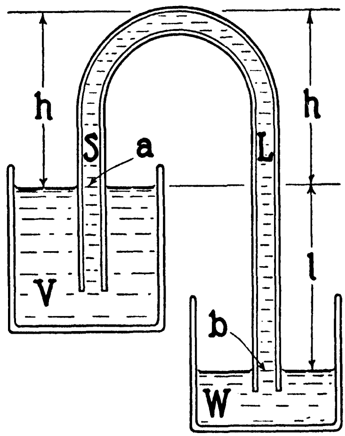


FIG. 87.—The siphon. (*Foley.*)

vacuum in the pipe, and water is forced up to a height of 30 feet by atmospheric pressure. It is evident that the piston must be within 30 feet of the water surface in the well if the pump is to

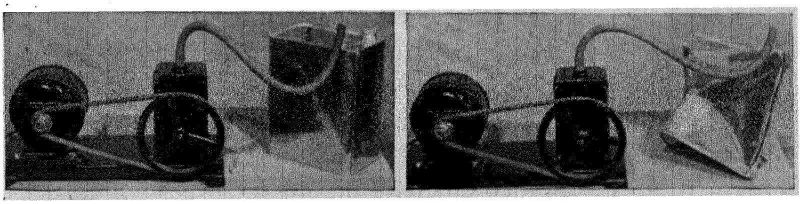


FIG. 88.—Illustrating the effect of atmospheric pressure. The can on the left is at atmospheric pressure. Some air has been exhausted from the can on the right.

operate. The siphon (Fig. 87) is another interesting application of the pressure of the atmosphere. The device is used to transfer a liquid from one container to another at a lower level. A siphon cannot be used to drain liquid from a lower to a higher level.

Many a householder has tried in vain to drain the cellar by placing one end of the hose on the lawn.

An interesting experiment for illustrating the great force of the atmosphere can be performed in the following way: Some water is placed in a empty can with a small opening. The water is boiled with the can open so that the steam will force the air from the can. After the water has boiled vigorously for about one minute, the can is removed from the flame and closed with a cork. As the water vapor condenses, a partial vacuum is created in the can and the force on the outside crushes the can (Fig. 88). A variation of the experiment is to exhaust the air with an air pump.

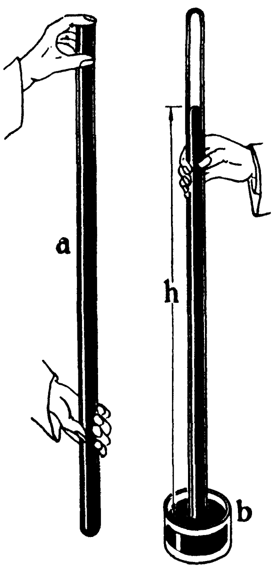


FIG. 89.—The barometer. (*Foley.*)

MEASUREMENT OF AIR PRESSURE

The barometer is the instrument used to measure air pressure. It can be made by filling with mercury a stout glass tube about 33 inches long, sealed at one end. A finger is placed over the open end (Fig. 89) and the tube inverted in a dish of mercury. A column of mercury approximately 30 inches high will remain in the tube, being supported by the air pressure on the mercury in the dish. As the air pressure varies, the height of the column changes. Figure 90 illustrates a commercial barometer.

Imagine a similar tube of air reaching out into space to the top of the atmosphere and resting in the dish of mercury beside the closed tube. The short column of mercury in the closed tube balances the long air column. As the air pressure varies, the height of the mercury column changes. If the air is lighter, the mercury falls. There is a definite relation

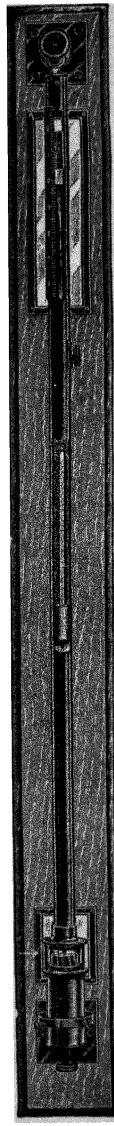


FIG. 90.—A barometer. (*Central Scientific Company.*)

between the mercury reading and the weather. Low barometers usually indicate storms, while high barometers usually mean clear weather. In a storm area the cyclonic effect produces a partial vacuum and the barometer falls. In clear weather the air is usually dense and contains less water vapor.

Mercury is generally used instead of other liquids in barometers for the following reasons:

1. Its specific gravity (see p. 413) is 13.6. It is the heaviest liquid known at ordinary temperatures. This makes a short column possible. Were water used, the barometer would need to be about 35 feet high.

2. Mercury does not wet glass.

3. It is quite easily visible.

4. Mercury boils at 357°C. and freezes at -39°C., so that it can be used over most of the earth.

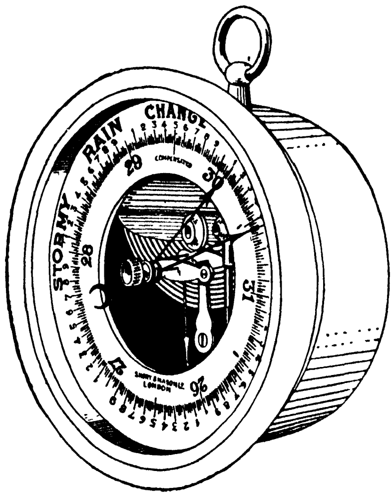


Fig. 91.—An aneroid barometer. (*Weld and Palmer.*)

It is possible to make a water barometer and there is an interesting story in connection with the first one ever made. Von Guericke, while studying atmospheric pressure, erected a long tube closed at one end reaching from the cellar to the roof of the house. A wooden image was placed within the tube floating on the water. On fine days this weather prophet would rise above the housetop, while in foul weather—at its approach in fact—he would retire below the roof. The superstitious citizens of Magdeburg thought that Von Guericke was in league with the devil. We must remember that this experiment was performed in 1650 rather than in modern times.

Another type of barometer, the aneroid, consists of a shallow cylindrical box with flexible cover. Most of the air in the box is removed. The flexible cover (corrugated to enlarge its surface area) rises and falls as the air pressure varies, its motion being transmitted to a pointer by means of levers. This type of barometer is both sensitive and portable. Because the atmospheric

pressure decreases with altitude, aviators use a modified form of the aneroid to measure height. A good altimeter can measure a height change of *two* feet. Figure 91 illustrates a common type of aneroid barometer.

COMPRESSED AIR

Compressed air is capable of exerting great force and is put to work in many devices. We are familiar with the signs on the rear of some trucks and buses—"Caution Air Brakes." Railroad trains and trolleys would be unable to travel at such fast speeds if they were not equipped with air brakes which enable them to stop quickly. Compressed air is used to spray paint, to sand-scour the outside of stone buildings, to operate drills, and to do hundreds of other things. It is one of our cheapest and most efficient tools.

When under-water tunnels and the foundations for bridges are being built, huge tanks called caissons are used. These are heavy and bottomless. They rest on the bed of the river. In the upper part are two or more chambers, each sealed. Men go down into the first and remain until they have become accustomed to the slight increase in pressure which is maintained there. Then they descend to the next chamber to a further increase of pressure. When they have become accustomed to this pressure, they go to the bottom of the caisson where they work under great pressure on the floor of the river, removing mud and laying foundations for the structure. Air under high pressure is continually forced into the caisson to keep the water out. (Fig. 92.)

Men cannot work more than a few hours a day under such pressure and are unable to work at this occupation for many years. They frequently succumb to a condition known as "caisson bends." Under such great pressure, an excessive amount of air is forced into solution in the blood. Nitrogen cannot be removed by body cells, so that when a man comes to the surface too rapidly the nitrogen, being unable to escape from the blood through the lungs rapidly enough, bubbles out into the blood vessels. This is the reason why men cannot leave a submerged submarine and rise to the surface of the water, unless special means are provided.

BUOYANCY

Buoyancy is the tendency of liquids and gases to support objects immersed in them. Because of the buoyancy of water, ships travel the seas and animals can float and swim. The principle of buoyancy was first stated by Archimedes, the philosopher of

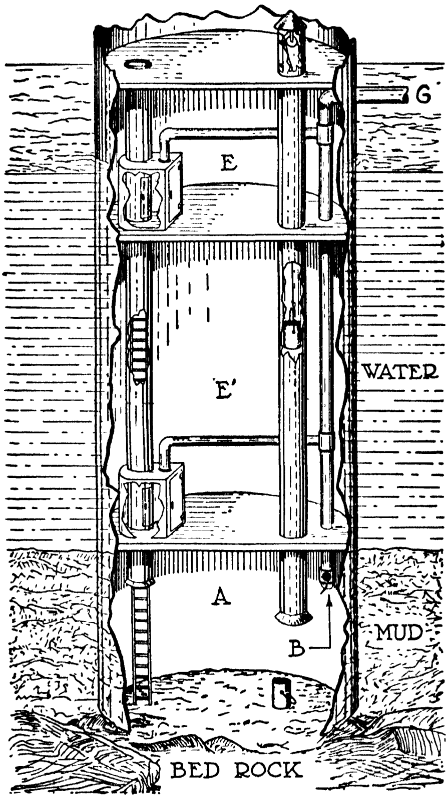


FIG. 92.—A caisson. (*Bowden.*)

Syracuse. *A body immersed in a liquid or a gas is buoyed up by a force equal to the weight of the displaced fluid.* A consequence of the principle is that objects which do not weigh more than an equal volume of gas or liquid, float.

Buoyancy will be described further under the subject of water in Chapter 25. At this point we shall illustrate it as follows: 10

cubic feet of air weigh about 12 ounces. Suppose that we have a balloon of 10 cubic feet capacity weighing one ounce. If this is filled with 10 cubic feet of air it will weigh a total of 13 ounces and will not float in air. The buoyant force is less than the total weight. However, if we fill the balloon with 10 cubic feet of hydrogen weighing only one ounce, the total weight will be 2 ounces instead of 13 and the balloon will rise in air. We can even tie objects to the balloon provided they do not weigh more than 10 ounces.

Now let us consider two other phenomena. Suppose our balloon without its load rises so high that it reaches air which, because of its rarity, weighs only 2 ounces per cubic foot. The balloon will stop rising and will float at that level. If the sun shines upon the balloon heating the gas and causing it to expand the balloon will be larger than 10 cubic feet, will weigh less per cubic foot than the air, and will rise higher. Or if, with the coming of night, the gas is cooled, shrinking to less than 10 cubic feet, the balloon will sink. In the stratosphere flight of Anderson and Stevens, the bag was initially only one-third inflated, so that upon rising to higher altitudes the expansion would increase the lifting power. They began the ascent before sunrise. Why?

In order to explain the term lifting power, let us consider a balloon of capacity 10,000 cubic feet filled with hydrogen of density .0056 pounds per cubic foot. The weight of the gas is 56 pounds. Since the balloon displaces 10,000 cubic feet of air of density .08 pounds per cubic foot, the buoyant force is 800 pounds. The lifting power of the balloon is thus 800-56 or 744 pounds. (We have neglected the weight of the bag.)

Balloons are large bags filled with hydrogen or helium to which a basket is attached. They depend upon the wind for motive power and direction of flight, as they cannot be steered. When they are released from the ground, they rise until they displace a weight of air equal to their own weight. As they reach warmer and lighter air, they sink.

The balloonist can cause a balloon to rise higher by emptying sand-bags, which are carried as ballast. He may cause the bag to descend by opening the valve in the bag, thus allowing the gas to

escape. *Since the balloon weighs less after some gas is removed, why does the balloon descend?* This question is left as an exercise for the student.

Although blimps and dirigibles are maintained in the air by rigid gas compartments, they are propelled by motors. When they wish to descend, air is pumped into reserve tanks, thus increasing the weight. The hydrogen or helium is not disturbed.

Airplanes are propelled by motors and are maintained aloft by the pressure of the air beneath them (see p. 225). The shape and curvature of the wings have been carefully calculated to produce a maximum of pressure under the plane. By means of whirling propellers, an artificial wind is maintained to keep the plane in the air.

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PROBLEMS

1. Why do balloons tend to rise when the sun heats the enclosed gas?
2. What is meant by fractional distillation?
3. Why are some mountains snow-covered in summer, while adjacent valleys are uncomfortably warm?
4. If you were 12 miles up in the atmosphere could you see to read a book? Explain.
5. Can you suggest a way by which a submarine could descend into the water?
6. If I open a bottle of ammonia at one point in a room, within a few seconds, the odor is detectable everywhere. Explain.
7. A balloon and contents weigh 500 pounds. It displaces 800 pounds of air. What is the lifting power?
8. Why do we use a straw to suck lemonade?
9. What does a mercury barometer indicate?
10. Why not use the aneroid barometer exclusively and discard the mercury barometer?
11. A tank of air at atmospheric pressure has the pressure tripled. How will the volume change?
12. 500 cubic centimeters of air are heated from 0°C. to 50°C. How will the volume change? An increase of 91 cc.

TOPICS

Dirigibles.	Heliocopters.	Priestley.
Liquid Air.	Airplanes.	Stratosphere Flights.

VISUAL AID

LIQUID AIR—General Electric Co.

EXPERIMENTS

1. *Oxygen.* Heat a mixture of equal parts of potassium chlorate and manganese dioxide in a pyrex test tube. Collect some of the gas in bottles and test it by glowing splints and by red hot picture wire. (Consult any chemistry text.)

2. *Nitrogen.* This gas has no interesting properties and the reader may consult any chemistry text for a method of production.

3. *Carbon Dioxide.* Place a small amount of limewater (calcium hydroxide) in a shallow dish and expose it to the air for about an hour. White calcium carbonate will be formed and the limewater will turn milky. This proves the presence of carbon dioxide in the air. To prove the statement, place some hydrochloric acid on marble chips and cause the gas which is evolved to pass into limewater. To show the presence of carbon dioxide in the breath, bubble the expired air into limewater.

4. *Water.* A glass of ice water is sometimes covered with a film of moisture which has condensed from the air. Dew is another illustration of water condensed from the air. (See Chapter 12.)

5. *Dust.* Allow the sunlight to shine through a tiny slit into a darkened room. Dust particles will be seen floating in the beam.

6. *Weight of the air.* Balance two corked flasks on a pan balance. Uncork one and heat it until it is quite hot. Remove it from the flame and quickly cork it. When it is cool, replace it on the pan. Is there still a balance? Explain.

7. Boil a few cubic centimeters of water in a flask, remove it from the heat and tightly tie a sheet of rubber over the mouth. Explain what happens.

8. Purchase a toy model airplane and examine the wing structure.

9. If liquid air can be secured, perform some of the common experiments.

12

WINDS AND WEATHER

"To talk of the weather, its nothing but folly,
For when it rains on the hill, it shines in the valley."
Denham

IN THE preceding chapter, it was stated that there is a relation between varying air pressure and the weather. The weight of air over a large heated area is less than the weight of an equal volume of surrounding cooler air, hence the warm air slowly rises or floats upward. As it floats upward, more air from the surrounding areas flows in toward the center of the heated area, and this, too, rises. Over a large cool area, the air, being dense and heavy, sinks and flows away as it reaches the ground. Between these two areas, air is in a horizontal motion. *This horizontal motion or movement of air is a wind. The vertically moving air constitutes a calm belt.*

We notice this at the seashore during the summer. Land absorbs and loses heat more rapidly than the water. During the day, the land is being warmed by the sun. As warm air rises, cooler air from the ocean flows toward the land giving us our afternoon sea breeze. At night, the land cools more rapidly than the water, so that the cool air flows out from the land. This is the Atlantic land breeze. These breezes contribute to our comfort at the sea shore. Anyone who wishes to sleep in comfort at Atlantic shore resorts should secure a hotel room which has windows on the west side of the building.

Weather is greatly influenced by belts of prevailing winds. There are on the earth four large regions of rather constant wind motion, known as wind belts (Fig. 93). Separating the wind belts are regions of no wind, called calm belts. Because each belt merges gradually into the adjacent belts and also because air movement is modified by the unequal heating of land and ocean masses, no definite boundaries can be given for each belt, so that

the latitudes noted in the diagram are only approximate. The belts shift about 5 degrees north in the summer and about 5

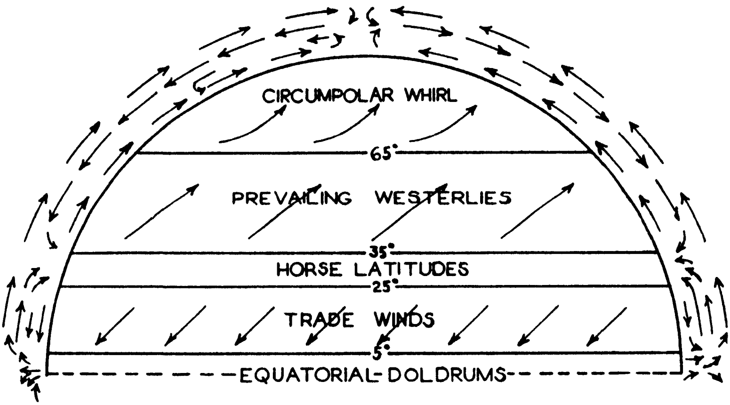

FIG. 93.—Wind belts of the northern hemisphere. The rising air of the doldrums flows north in the upper atmosphere and gradually drops at the horse latitudes. This air returns as the trade winds. Another part of the upper air forms the prevailing westerlies.

degrees south in the winter. Milham ("Meteorology" page 170) lists the following data:

	Atlantic		*Pacific*	
	March	*September*	*March*	*September*
Northeast Trades	26°N. to 3°N.	35°N. to 11°N.	25°N. to 5°N.	30°N. to 10°N.
Doldrums	3°N. to 0°N.	11°N. to 3°N.	5°N. to 3°N.	10°N. to 7°N.
Southeast Trades	0°N. to 25°S.	3°N. to 25°S.	3°N. to 28°S.	7°N. to 20°S.

WIND BELTS

Of all regions, the equatorial zone receives the greatest amount of heat from the sun. This is partly because of the approximately equal days and nights, but primarily it is due to the fact that the equator is receiving direct rather than slanting rays

of sunlight. A beam of sunlight one foot square striking the ground from directly overhead heats one square foot of ground, whereas the same beam striking the ground from an angle distributes the same heat over several square feet. Each square foot receives correspondingly less heat.

This can be demonstrated by using a flash light and a long tube with a wide collar around it. Flash the light through the tube onto a sheet of white paper in a dark room. Note the difference in illumination on the paper as the rays change from vertical to slanting.

The result is a rather steady upward flow of air. Because the air is moving upward over a great area, no wind is felt, hence the equator is a belt of calm (*doldrums*). Most of the equator lies over water and, as there is more water vapor in warm air than in cold air, the rising air over the equator is "saturated with moisture." As the air reaches an altitude of a few thousand feet, it expands and in expanding becomes cool. This accounts for the low temperatures which prevail in the troposphere over the equator. As the air cools some of the water vapor condenses, consequently there are almost daily downpours of rain over the equator. At the equator the weather is about the same from day to day. The nights and early mornings are usually cool. The temperature and humidity rise during the forenoon, after which a heavy rain occurs.

TRADE WINDS (Steady Winds). Air is continually being pushed toward the equator, ever replacing the upward moving air of the doldrums. This results in a belt of steady winds, known as the trade winds, on either side of the equator. The *trade winds* become warmer as they approach the equator, hence more moisture may evaporate so that rainfall is rather infrequent.

Were it not for the rotation of the earth, the trade winds would blow directly toward the equator from north and south. *However, because the earth is rotating on its axis from west to east, the winds acquire a westerly direction, coming from the northeast and southeast.* (Winds are named from the direction from which they come, hence Northeast and Southeast Trades.) A point on the equator is moving about 25,000 miles in 24 hours, more than 1000 miles per hour. A point on the earth at latitude 45 degrees,

is rotating only about 700 miles per hour, while a point near the pole has very little motion of rotation. Since the moving air tends to retain the rotational speed of the point whence it comes, the winds moving from latitude 45° toward the equator fall behind the earth, thus acquiring a westerly direction of flow. The direction of air flow is stated by Ferrel's Law: *To one facing the equator, moving wind and water are deflected toward the right in the northern hemisphere and toward the left in the southern.*

An illustration of this effect is furnished by a merry-go-round. Suppose that the person on the moving platform decides to walk across the platform directly toward a point in the building. Because the platform is moving ahead as he walks across, he will walk diagonally across the platform. Another illustration is to rotate an earth globe counterclockwise, while a chalk line is drawn from the north directly south. The chalk line will be found to be curved.

ANTITRADE WINDS. As the heated air rises to a height of about 6 miles at the doldrums, it is cooled by expansion and deflected by the rotation of the earth. This air flows poleward in the upper troposphere (weather sphere) forming *antitrades.* These winds are very complex due to irregularities of temperature. Some of this moving air gradually settles to the earth, forming two calm belts known as the *horse latitudes.* Because the air is dense and has little water vapor, rainfall is infrequent in these calm belts. Some of the region is desert.

PREVAILING WESTERLIES. Much of the air flows further poleward, forming the great belts of *prevailing westerlies* in the temperate zones. The direction of air flow is due to the fact that the anti-trades are blowing poleward, that is, from the equator to points which are rotating more slowly. This has the effect of deflecting the air eastward, hence "prevailing westerlies."

The movement of the westerly belt, a belt of irregular storms, is influenced by topography and other conditions. During the winter, the United States lies almost entirely in the westerly belt. During the summer, the southern tier of states lies in the horse latitudes. South of the equator, the westerly belt is almost unbroken by land so that the winds are strong and steady, being

referred to by sailors as the "roaring forties" (40°S to about 50°S). Around the poles, we have the so-called circumpolar whirl. The air movements of the polar regions have not been thoroughly studied as yet, but their study is one of the objects of numerous polar expeditions. The expeditions of Admiral Byrd studied the Antarctic air masses.

STORMS

The prevailing westerly belt is characterized by a succession of storm areas which are carried eastward by the general movement of air. These storm areas are regions of rising air, and are known as "*lows*" because the decreased pressure results in low barometer readings. Lows are small circular replicas of the doldrums. As the air in a low rises, it becomes cooled, frequently to such an extent that precipitation of rain or snow results.

In addition to the antitrade winds, a current of cold air drifts down from the poles. As this cold air layer meets the warmer equatorial air, it moves in under the warmer air causing a whirling motion. This is the cause of *cyclones*, those storms which move eastward across the United States and Canada. A cyclone may be a very feeble whirling mass of air or it may assume the dangerous speed of a tornado. Since the center of the cyclone is a *calm* (*low*), air blows toward this low from all directions where the pressure is higher (high). For this reason, a cyclone in the central part of Pennsylvania is forecast, on the eastern coast, by the easterly winds which blow from the Atlantic. An east wind means that a storm area is moving from the west. Winter storms generally move eastward about 700 miles per day, while the summer disturbances travel only 500 miles per day.

Tornadoes. A tornado is a rapidly whirling funnel of uprushing air, in the center of which there is a very low pressure. The tornado itself usually travels about 25 to 50 miles per hour, but the whirling air has a speed which has been estimated at from 100 to 500 miles per hour. When the center of the tornado passes over a building in which there is air at normal pressure, an explosion may result causing the walls of the building to be blown outward. (If possible, it is desirable to open doors and windows in

the path of a tornado so that the air pressure inside and outside of the house may be equalized.) Tornadoes are of short duration and cover a narrow path (Fig. 94). The region between the Rockies and the Appalachians seems to be best suited for the development of such storms. The exact cause of tornadoes is not known, but it is believed that currents of air blowing in opposite directions at about the cloud level develop a tremendous whirl. It is estimated that tornadoes take the lives of about 300 people each year. In other parts of the world such destructive storms are called *hurricanes* and *typhoons*.

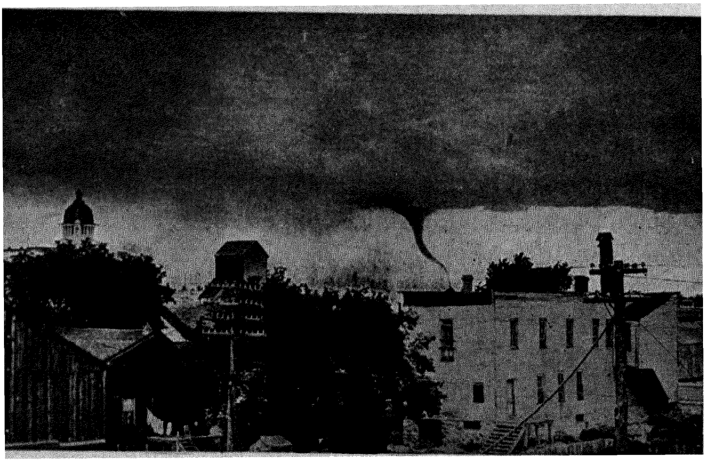

FIG. 94.—A tornado. (*Bowden.*)

HIGH PRESSURE AREAS. There are also regions of cool, descending air known as "high" areas, because of their high air pressure and high barometric readings. In the center of highs and lows the movement of air is vertical, constituting a calm. Shortly after the beginning of a storm, the wind stops for an hour or so while the very center of the low passes over. After this calm period the wind begins to blow from a different direction.

WINDS. Air moving from a high to a low constitutes a wind. Winds are strong when the difference in pressure between the high and low is great, also when the high and low are close together. If the pressure difference is not great, we have gentle breezes. An average high is about 30 inches and a low averages

29.5 inches. If the pressure drops to 28 inches, a hurricane is approaching.

Precipitation in a Low. Rain or snow starts at about the center of a low, or very slightly in advance of it, and continues until the low has moved well past. After the low has passed, the weather is usually clear and cooler. However, rain or snow do not necessarily accompany every low. Sometimes the sky is clear, sometimes overcast; sometimes there are scattered showers rather than widespread rain. Numerous conditions, some of which are little understood at present, contribute toward making rainfall. The most important is that water vapor must be cooled below its saturation point. Even in this case, it sometimes happens that the raindrops revaporize before reaching the ground and no rainfall occurs.

Thunder Storms. We are all familiar with the afternoon or evening thunderstorms which frequently occur on a clear, hot, day during which there has been very little or no wind. Intense convection currents have been set up as a result of these conditions. Cold air rushes down in the rear of the advancing uprushing air. Condensation occurs as the air is cooled, forming the familiar *cumulo-nimbus* clouds, dark, flat-bottomed, and billowing. In such clouds, the water droplets are large. Winds blow toward the approaching storm. As its center approaches, gusty winds are noticed and a heavy downpour of large raindrops occurs, finally settling down to a steady rain.

Thunderstorms cannot occur unless there has been a great evaporation of moisture with resulting high humidity. They may occur at any hour of the day and in any season, even during the winter. Thunderstorms are usually caused by very cool layers of upper air flowing over moderately warm air, or by cool currents flowing in under warm air. We do not have thunderstorms very often in the winter because the high humidity and rapid evaporation are usually absent.

HUMIDITY

The amount of moisture in the air depends upon its temperature. By moisture, in this case, we refer to gaseous water rather

than rain, fog, or water in any liquid or solid form. Appendix IV gives us the relation between temperature and water vapor. The humidity is expressed either as grams per cubic meter, or as relative amount of water vapor present (see Experiment 3). The first is termed *absolute humidity* and the second *relative humidity.*

Even in air which seems very dry, as air over a desert, there is some water vapor. The desert in northern Africa has a relative humidity of 10%. The water vapor in the air prevents excessive cooling at night. On the Sahara, the nights are very cold because of the low humidity. Water vapor also prevents excessive evaporation. During the summer of 1930, much of the United States experienced a drought. It was said that the grass and trees burned up. They did not, however, as the temperature averaged very little if any higher than usual. Plant life did dry out to such an extent that it died. This was due to the excessive evaporation from the leaves. Plants such as cacti, whose habitat is a dry region, are protected against excessive evaporation by having small leaves (spines and needles) and few stomata.

A Correct Statement of Humidity. It is customary to say that air holds moisture and that at a high temperature air can hold more moisture than it can hold at a low temperature. This phraseology is erroneous. Dalton's law states that each constituent of a mixture of gases exerts a pressure independent of the pressure of the other constituents. Suppose that there is a beaker of water under a bell jar from which some air has been removed (a partial vacuum). Water evaporates until the space within the jar becomes saturated. If we now admit air to the jar, water vapor will not condense nor will more water evaporate. The pressure of the water vapor upon the sides of the jar is totally independent of any air pressure inside the jar. *In other words, the presence of air has nothing to do with the evaporation of water which is dependent upon only two factors, temperature and water vapor already present.*

It is correct to state that the air is saturated with moisture. We must remember, however, when we speak of a cubic meter of air holding a certain amount of water vapor that we really mean a cubic meter of space. *One must not forget that water vapor is a*

colorless gas and not a liquid. Such expressions as "the air is full of water" are "bad science."

Dew Point. Most persons use the expression "the dew is falling." Dew does not fall but it is the condensation of water vapor on the grass at night because of the cooling of the air around the grass. The temperature at which the air becomes saturated is known as the dew point. The condensation of moisture on a pitcher of ice water indicates that the air immediately in contact with the pitcher has been cooled to the dew point. By the use of the dew point we can determine relative humidity (see p. 177).

Control of Body Temperature. The amount of water vapor surrounding us has such a great influence upon our comfort that we frequently confuse temperature with humidity. We are endowed with several methods for increasing or decreasing body heat in order to maintain a rather constant temperature of about 98.6°F.

One of these methods is the evaporation of moisture, called perspiration, from the skin. When the humidity is high, moisture does not readily evaporate from the skin, just as clothes fail to dry when hung out on a day having excessive humidity. As a result, body heat is not dissipated; we feel warm, damp, and uncomfortable. In warm weather, much moisture is brought to the skin in an effort to reduce the body heat. If the moisture (perspiration) does not evaporate, due to the high humidity, we feel damp and uncomfortable. On the other hand, if the humidity is too low, we feel restless; moisture leaves the skin too rapidly and we feel dry. The tissues of the nose and throat become irritated and subject to infection. Most physicians believe that a relative humidity of about 40% is most satisfactory. To attain this is one of the aims of *air conditioning apparatus* (see p. 173).

Measurement of Humidity. Some materials are quite sensitive to moisture. They may shrink, stretch, or change color with changes of humidity. Devices which are reasonably accurate for measuring relative humidity can be made from them. One such device, the *hair hygrometer*, is made by fastening one end of a long hair to a rigid box and the other end to a wheel kept under

tension by a spring. As the hair stretches, the spring curls it around the wheel; as the hair shrinks it unwinds. A long human hair which has had its oil removed by alcohol is frequently used. White human hair increases its length by $\frac{3}{128}$ when transferred from dry to saturated air. Such devices are not very accurate and are really *humidiguides*, as they indicate the humidity, but cannot predict the weather. Their value as weather prophets depends upon the fact that the humidity is usually greater in a low than in a high pressure area. They are often made in the form of novelties, one of which is the familiar little doll which moves in and out of a house as weather changes are expected. The "chemical garden" is another illustration of the effect of humidity.

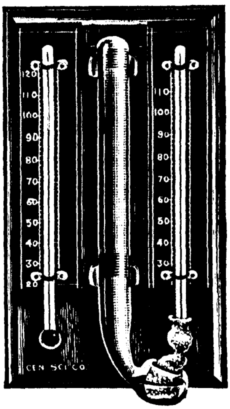

FIG. 95.—Wet and dry bulb hygrometer. (*Courtesy Central Scientific Company.*)

Relative humidity may be measured to an accuracy of within 5% by wet and dry bulb thermometers. There are several forms of this apparatus on the market (Fig. 95). The dry bulb measures actual room temperature. The bulb of the other thermometer is covered by a wick which is soaked in water. In very dry air, moisture evaporates rapidly from the wick lowering the temperature. Moist air causes slow evaporation and only a slight depression of the thermometer. It is important to emphasize that the difference in temperatures is not a direct measure of the relative humidity. Tables must be used for a humidity determination (Appendix III).

PRECIPITATION. It was stated on a previous page that the moisture which can be present depends upon its temperature. The temperature at which the air becomes saturated with moisture is known as the dew point. After sunset, the heat of the land is radiated out into space. As the air immediately in contact with the ground becomes cooled below the dew point, moisture is condensed as dew on the ground. Dew is not formed on a cloudy night because the clouds hinder the radiation of heat from the earth. On windy nights, the air does not remain in contact with the ground long enough to reach the dew point.

FROST. Frost is composed of the spicular ice crystals which are formed when the dew point is below the freezing point of water; the water vapor then changes directly into ice crystals. Contrary to popular belief, frost is Nature's protection for vegetation. Frost does not kill plants, but the unequal and too sudden expansion which takes place on freezing does the damage. Hoarfrost is formed when very humid air is in contact with objects which are below the freezing point; it covers trees, fences, and higher objects, and is thicker than ordinary frost.

FOG. Fog is formed when rather humid air in gentle horizontal motion is cooled below the dew point. Dust particles aid in the formation of fogs, which accounts for the London fogs which form on clear mornings after work has started in the factories. Fogs over the ocean south of Newfoundland are due to warm, moisture-laden air blowing from the Gulf Stream across the cold, southward-flowing Arctic Drift which passes under the Gulf Stream in that locality. The individual fog particles are of colloidal size; they may coalesce to form larger particles which fall as rain or they may revaporize as the air becomes warmer. An interesting use of fog is in the study of charged particles such as electrons and alpha rays. This use is discussed in Chapter 13.

RAIN AND HAIL. Rain is formed by rapid condensation of water vapor. The character of the storm determines the size of the drops. Rapid summer convection currents form large drops, while the whirling currents of winter air or strong winds produce small drops. Raindrops freeze, forming sleet, when falling through air which has a temperature below 32°F. Hail is produced when drops of water are carried by the convection currents of air into a stratum cold enough to freeze them. As they become heavy they fall back into lower altitudes and become covered with water and, upon being hurled upward again, receive another coat of snow and ice. The hailstones soon grow so large that they are too heavy for further tossing upward and they fall to the ground. The size of the stones may be as much as an inch or more in diameter. By slicing a hailstone, one may see the successive layers of ice.

SNOW. This is the result of condensation at a temperature below 32°F. In other words, rain forms and falls as liquid water; sleet forms as a liquid but freezes before it reaches the ground;

snow crystals are formed in freezing air and reach the ground in a crystalline state. They are not ice. Each snow flake grows into a beautiful six pointed crystal as it is being formed. Over one

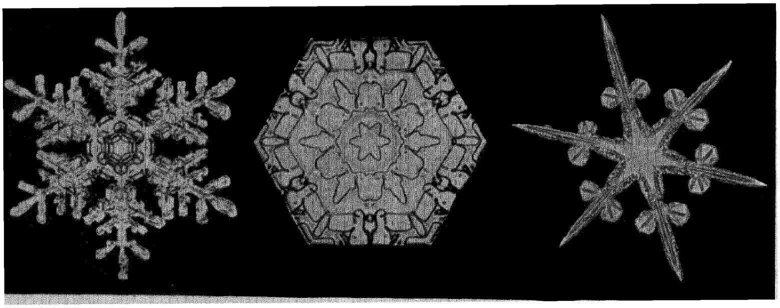

FIG. 96.—All snowflakes are hexagonal crystals. (*Science Service.*)

hundred thousand separate flake forms, all variants of the six pointed crystal, have been noted. Our knowledge of snowflake patterns is largely due to the work of Wilson Bently of Jericho,

FIG. 97a.—Cirrus clouds. (*Bowden.*)

Vermont, who made a hobby of photographing the flakes under the microscope. Figure 96 shows a few of the pictures.

CLOUDS. It may seem strange to describe clouds in connection with precipitation, but clouds actually consist of water droplets,

snow, or ice, sustained in the air by convection currents or wind (Fig. 97). *Cumulus* clouds are the light, fluffy, flat-bottomed

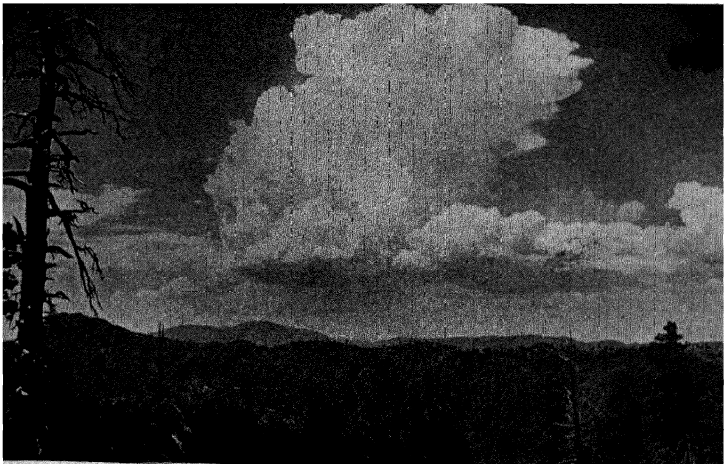

FIG. 97b.—Cumulo-nimbus clouds. (*Bowden.*)

FIG. 97c.—Cumulus and strato-nimbus. (*Bowden.*)

clouds which appear during an afternoon. They are formed by condensation of moisture as the rising air reaches its dew point, usually about one mile above the ground. *Cirrus* (curl)

clouds consist of ice particles and are often 5 or 6 miles up. As a rule they are thin, beautiful, feathery forms and sometimes cause the halos around the sun and moon. *Cirro-cumulus* clouds, two to four miles high, give the appearance of a "mackerel" sky. *Stratus* clouds, as the name suggests, seem to be in layers or streaks. They may be rather close to the earth and are often accompanied by rain. *Nimbus* clouds are rain clouds, dark, massive, and usually formless. They are about one mile high. As has been stated, the thunderstorm cloud is called a cumulo-nimbus.

WEATHER

THE CAUSES OF WEATHER. A very close correlation has been found to exist between variations in solar radiation and variations in the weather. Three stations have been established to study the hourly variations in solar radiation and variations in the weather. One of these stations is in California, one in Chile, and one in Africa. They must be located where there is a maximum of sunshine and a minimum of dust and haze.

Another cause of weather irregularities is the polar air. Many of the storms which pass over the United States seem to originate in Alaska. From "Greenland's Icy Mountains" weather receives further stimulation. Low pressures which leave the United States as gentle storms become fiendish hurricanes after passing south of Greenland. This may be due to the continual high pressure existing on the Greenland continent.

WEATHER FORECASTING. The Weather Bureau receives two weather reports each day from a network of stations covering the entire North American continent. Such reports give barometric pressure, temperature, wind direction and velocity, precipitation, type of weather. In addition, reports are received from many vessels in coastal waters. Pilot balloons and airplanes are used to secure information concerning conditions in the upper air layers. From these reports the daily weather map is made and the weather predictions are issued. The United States lies in the belt of prevailing westerlies, hence its storm areas travel from the Pacific coast to the Atlantic. The weather forecasts are based upon the weather conditions to the west of us. Numerous factors

such as the proximity to other cyclonic or anticyclonic areas and differences in pressure, temperature, and topography must be considered in making the prediction. Rather accurate forecasts can be made for 48 hours in advance. The Weather Bureau performs valuable service in airplane flights by giving complete information about the upper air. By means of its predictions shippers can protect fruit and vegetables, and orchardists can guard against freezing temperatures. We all use the weather forecasts in our daily activities.

The Weather Bureau performs excellent service in forecasting weather. Some curious mistakes often occur. On the occasion of the inauguration of President Taft on March 4, 1909, the Weather Bureau predicted fair weather. They felt safe in making the prediction inasmuch as the entire country had a fairly high pressure. Consequently, thousands of people flocked to Washington for the inauguration. On the evening of March 3, a small low developed in the Carolinas, so that by the morning of the inauguration, the streets of Washington were covered ankle deep in slush, and rain was falling. The visitors suffered much inconvenience, and as a result, the newspapers subjected the Bureau to a good deal of friendly ridicule.

Why are east winds an indication of rain, and is this method of forecasting accurate? A low is the center of low air pressure; air is flowing into it from all directions. The low moves eastward. As it arrives within approximately 500 miles to the west of us, we begin to notice the movement of air toward it (east wind). The eastern United States and eastern Canadian winds are moisture-laden but, since this air becomes warmer and expands as it approaches a low, no precipitation can take place until that air actually rises within the center of the low, spreads over it, and becomes cooled below its saturation point. Hence, we see that an east wind heralds the approach of a low or storm area. This explains why weather predictions are based on actual weather conditions to the west of us (Figs. 98–99).

WEATHER MAPS. Each day the Weather Bureau issues a chart giving weather predictions and conditions for the entire country. The map is marked with black lines of equal pressure

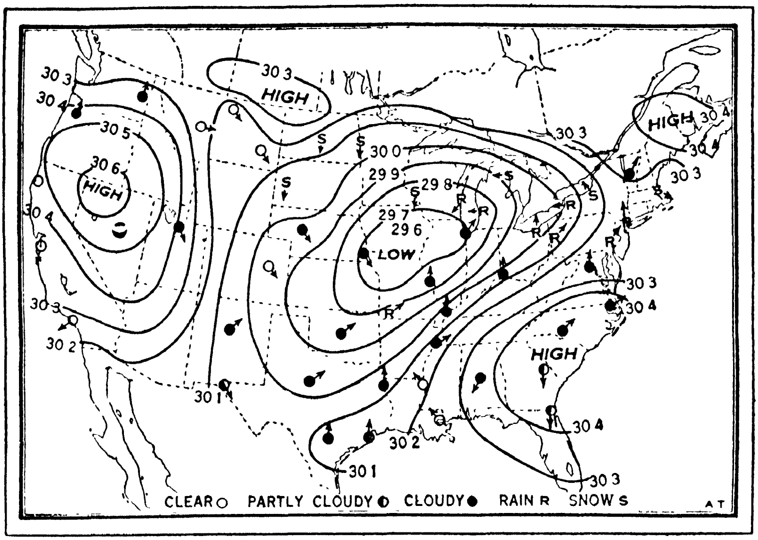

FIG. 98.—A typical weather map. (*Bowden.*)

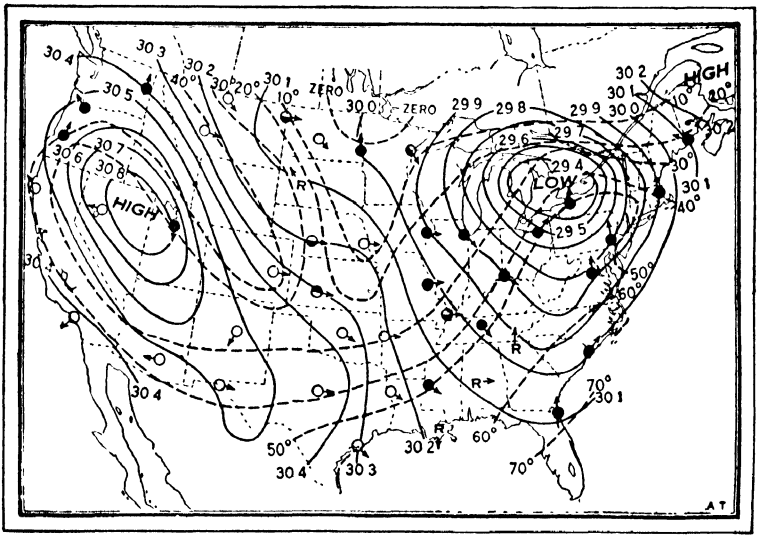

FIG. 99.—Weather conditions 24 hours later than conditions shown in Fig. 98. (*Bowden.*)

(isobars). There are red lines passing through locations having the same temperature (isotherms). The wind directions are indicated by arrows, and the type of weather by the shading of the arrows. The Bureau also gives information so that the reader may learn to predict weather from the conditions to the west.

We quote from the weather map, as follows:

"In general, a high indicates fair weather. Lows usually represent stormy conditions. If the wind sets in from the south or southeast and the barometer falls steadily, a storm is approaching from the west or northwest, and the center will pass near the observer within 24 hours."

Within the last year a tiny radio transmitter has been devised which can be connected to a pilot balloon. As the balloon rises, the device sends out each minute, messages which give the temperature, pressure, and humidity. By this means the upper air can be studied without the necessity of an airplane flight.

AIR CONDITIONING

It can no longer be said of the weather that "everybody talks about it but nobody does anything about it." The scientific business of air conditioning (artificial weather making) is rapidly assuming importance. Unsatisfactory atmospheric conditions lower human efficiency, initiate illness, destroy property, and cause great discomfort. In winter, the air needs to be heated and humidified. In summer, we require cool air which has moderate humidity. At all times we need circulating, clean air. For these reasons, office buildings, theaters, railroad coaches, department stores, and homes are being equipped for controlled air conditions.

Air conditioning has been defined as the science or process of maintaining any desired temperature, purity, moisture content, and air motion within an enclosure. Man's first attempt at air conditioning was an open fire in a cave. This was followed by fireplaces, stoves, furnaces, and electric heaters. These raised the temperature, but did not attempt to improve other factors. Until rather recently, few attempts were made to provide proper humidity. Many people have attempted to increase humidity by placing pans of

water on the stove and by using water jackets in the hot air furnace. It was impossible to provide proper humidity by such hit or miss methods. It would be necessary to evaporate several gallons of water each day to provide proper humidity by such devices.

In the ordinary home in the winter, cold air having a rather low humidity is heated without the addition of moisture. This means that the relative humidity is lowered. *For example, if we use outdoor air having a relative humidity of 30% at 40°F., and heat this air to 70°F., Appendix IV shows us that the relative humidity is now only about 10%. We have lowered the humidity by heating the air.* Consequently, moisture must be added. Conversely, when warm air is cooled the humidity is increased. Most authorities agree that the best conditions for comfort are a temperature of 68°F. and a humidity of 40%.

Body warmth is influenced by humidity and by air circulation as well as by temperature. This is determined by the rate of evaporation of moisture from the body surface. Thus we feel cooler in hot, circulating, dry air than in nearly saturated air at a lower temperature. For example, 90°F. and 20% relative humidity are more comfortable than 75°F. and 70% relative humidity. Conditioning engineers use the term *Effective Temperature* to include all the factors just mentioned. We have all been aware of discomfort when sitting in a closed theater which was not air conditioned. The feeling of lassitude and depression was due to a combination of high temperature, high humidity, and a poor circulation of air in the room. On the other hand, a low humidity causes a rapid evaporation of perspiration. As has been stated, physicians attribute many throat ailments to overheated, dry rooms.

AIR CONDITIONING EQUIPMENT. Three types of air conditioning are in use; ice, steam jets, and mechanical refrigerators. Some railroads are using all three in an attempt to determine the most satisfactory and economical process. In the ice system used on the Pennsylvania Railroad, water is cooled by being sprayed over cakes of ice. The cold water is pumped into cooling tubes, over which the air of the car flows. This method is probably the most

economical but, the necessity for frequent icing is a disadvantage. In mechanical refrigeration,* a refrigerant such as "Freon" is used to chill the evaporator surface. The air is blown over this surface (Fig. 100). In the "steam jet" method, a steam jet produces a vacuum of about 29 inches in an insulated chamber. Water is sprayed into the chamber and because of the rapid evaporation, the water becomes chilled and is passed through cooling pipes over which air flows.

In all cases, air having a high humidity, is cooled below its dew point so that the air leaving the apparatus has a lower absolute humidity than it had when it entered. As this air is circulated through a building, the humidity is low enough for evaporation of perspiration to take place readily. During cold weather, air is passed over heated pipes as it leaves the humidifier so that the temperature and humidity are both raised.

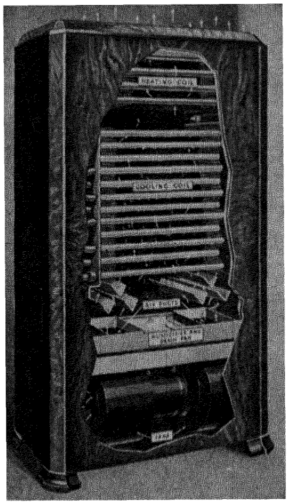

FIG. 100.—Air conditioning apparatus. (*Frigidaire Corporation.*)

The problem of dust removal is a vital part of air conditioning. If the air is bubbled through cold water, the dust is removed at the same time the humidity is lowered. Many large office buildings furnish relief for hay fever sufferers by removing the dust and pollen from the air. Not only must the air be cleaned and cooled, but it must be circulated by large fans.

Some of the important users of air conditioning are hospitals, theaters, flour mills, bakeries, paint shops. Any restaurant which can advertise that it has an air conditioned room is certain to increase its patronage. Many large department stores have air conditioned all or part of the plant. One large eastern store has air conditioned its basement and main floor with the result

* Mechanical refrigeration is often spoken of as electrical refrigeration. See page 246.

that the increased sales have paid for the installation in a single year.

Unfortunately, the cost of home air conditioning is still beyond the purse of the average home owner. Perhaps it may be possible to bring the cost down and if this can be done, we shall be able to produce the type of weather we want by the flip of a switch. We are doing something about the weather!

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TOPICS

Humidiguides.
Air Conditioning.
Tornadoes.
Hurricanes
The Climate of the Tropics.
Monsoons
Sargasso Sea.
Typhoons.

PROBLEMS

1. Explain the cause of the Great American Desert; the Sahara; the Australian.
2. Explain why moderate humidity is more comfortable than high humidity regardless of the temperature.
3. Why is low humidity in school rooms harmful?
4. Why does an east wind usually indicate the approach of rain?
5. What does the wet bulb read if the relative humidity is 76% at a time when the temperature of the air is 80°F.?
6. Why is there, usually, no frost on a windy night?
7. Explain the frequent fogs off the coast of Labrador.
8. Why does the Gulf Stream moderate the climate of England but not that of Canada? (See Chapter 8.)
9. Why is it incorrect to say that dew rises or falls?
10. Describe three methods for conditioning the air.
11. What are the doldrums? The horse latitudes?

12. Describe the wind cycle which causes the trade winds.
13. Why do the trade winds blow from the northeast instead of from the north?
14. What is a cyclone? a hurricane? a typhoon?
15. Explain the causes of a thunderstorm.
16. What is meant by relative humidity? by absolute humidity?
17. What causes snow, frost, sleet, hail?
18. What is meant by air conditioning?
19. What is a hygrometer? a humidiguide?
20. Explain why we may lower the humidity by washing the air with cold water.
21. What is the origin of the prevailing westerlies? Why do they move toward the northeast?

EXPERIMENTS

1. Use an air convection apparatus. Hold a smouldering stick over a lighted candle under one opening and then cover the other opening of the convection apparatus. How does this explain highs and lows?

2. Put 2 or 3 drops of water on a wooden block. On this, place a watch glass and fill it with ether. Fan it vigorously until the ether has evaporated. The crystal should freeze to the block. Explain.

3. Determine the relative humidity of the room by the dew point method. Place water and a small piece of ice in a clean, shining, metal can, the outside of which must be perfectly dry. Stir the water carefully. The instant that a film of water appears on the outside of the can, read the temperature of the water. Remove the ice, continue to stir, and note the temperature at which the moisture just disappears. Perform this several times. An average of the readings is the temperature at which the air in the room would be saturated with moisture. Suppose that the average reading is 59°F. By referring to Appendix IV, we see that at 59° the maximum weight of water possible is 12.71 grams per cubic meter. Suppose the actual temperature of the room, however, is found to be 80.6°, and at this temperature there can be as much as 25.49 grams of water vapor present per cubic meter. In other words at a certain time the temperature of the air in the room is 80.6° and so there may be possibly 25.49 grams of water present, but we find that there are actually only 12.71 grams present.

$$\textit{Relative Humidity} = \frac{\text{weight of water vapor found per cubic meter}}{\text{weight of water vapor possible per cubic meter}}$$

$$= \frac{12.71}{25.49} = 50\%$$

Note. During the winter, the absolute humidity in some schoolrooms may be so low that the dew point is below 32°F. In this case no moisture will con-

dense on the can and the relative humidity must be determined by the use of ether.

4. Determine the relative humidity by the wet and dry bulb thermometer (Appendix III).

5. Procure a weather map and answer the following questions about any city east of the Mississippi, about a city along the Gulf of Mexico, and about some location in the far west.

What was the temperature?

What was the pressure?

Was it raining?

Had there been rain within 24 hours?

What was the wind direction?

What was the probable weather for the following day?

This exercise is more profitable if maps for three consecutive days are studied and the weather then forecasted. A fourth map can be used to check the accuracy of the forecast.

6. Collect hourly data as to temperature, pressure, and sky for an entire school day. Make a forecast of the weather for the following day. On the following day, try to see why you missed your prediction or why your prediction was correct.

7. Secure information concerning the various types of air conditioning apparatus. Visit the local theater, the hospital, the department store. Secure information from your local railroad agent about air conditioned trains.

13
THE ATOM AND ITS RADIATIONS

"All things the world which fill
Of but one stuff are spun."

THE ATOM. Men have always wondered about the constituents of substances. We know that we can cut an iron wire into many small pieces. Is there a limit to which we can subdivide the wire, or is the wire so constructed that there is no limit to the possibility of subdivision?

The theory of limits in Geometry teaches us that if we cut a line in half, and cut the parts again in half, there is a possibility of subdividing in half forever. Some of the ancient Greeks taught that all objects were composed of small indivisible atoms, which were invisible. This means that the iron wire can be subdivided only to the extent that the atoms are isolated. On the other hand, Aristotle taught that one could chop a substance into finer and finer bits, never reaching an end.

Newton also believed that all materials were composed of small hard particles which could not be divided. In 1806, John Dalton, an English chemist and schoolmaster, put forth the *atomic theory of matter*. From his experiments, he concluded that each *element was composed of ultimate, indivisible, identical particles, and that the particles of different elements differed in weight.* Moreover, he concluded that the atoms combined to form molecules (little heaps), and that these molecules were the building stones of chemical compounds. Unfortunately, these atoms can not be made visible, because of the limitations of the eye and the microscope.

The ability to see a tiny object placed under a compound microscope depends on the property known as the resolving power of the instrument. The resolving power is defined as the ability of an optical instrument to enable the eye to distinguish

two objects which are close together. Although the resolving power increases as the color of the light used to illuminate the object changes from yellow to violet, it is not possible to see an object as small as an atom is believed to be. The best microscope, using blue light, cannot make any object visible which is less than 1/100,000 of an inch in diameter, and the atom is certainly much smaller than this.* Most experimental evidence leads us to believe that an atom is about 10^{-8} cm. in diameter. This means that an atom compares to a baseball as the baseball compares to the earth. We can study the properties, but we cannot observe the actual appearance of these tiny bits of matter.

Brownian Motion. The nearest approach that scientists have made to actual observations of atoms, molecules, and their motions, is by the study of the Brownian motion in colloids (see p. 407). In 1827, a botanist, Robert Brown, placed under a microscope a small dish containing pollen in water. He noticed that the grains were in constant motion. Later, Perrin made colloidal suspensions of very small particles of metal, and found these particles, each containing several thousand atoms, constantly moving about in the liquid. The dust particles seen floating in a beam of sunlight also show this motion. It is possible to produce a colloidal suspension (see p. 405) of metals such as gold, by allowing electrical sparks to pass between two gold electrodes immersed in water. There are other methods which involve chemical reactions. A very inexpensive piece of apparatus, which can be placed on the microscope stage, is now for sale. The cell is filled with smoke and illuminated by an arc lamp. It is possible to view the motion of the particles.

For convenience, the scientist makes use of an exponential number in writing very large and very small numbers, *e.g.*, one thousand is written 10^3, one million is written 10^6, and one millionth is expressed as 10^{-6}. Using this notation the diameter of the atom is 10^{-8} cm. There are 6×10^{23} molecules in 2 grams of hydrogen.

Periodic Table. In 1869, a Russian scientist, Mendeleeff (Fig. 101), discovered that there existed relationships between

* The new Grattan microscope which magnifies 3000 times may give a higher resolving power.

PERIODIC SYSTEM OF THE ELEMENTS

	I A	I B	II A	II B	III A	III B	IV A	IV B	V A	V B	VI A	VI B	VII A	VII B	VIII A	VIII	VIII	B	
1	1 H 1.008																	2 He 4.00	
2	3 Li 6.94			4 Be 9.02	5 B 10.82		6 C 12.00			7 N 14 008		8 O 16.00		9 F 19.00				10 Ne 20.18	8
3	11 Na 23.00			12 Mg 24.32	13 Al 26.97		14 Si 28.06			15 P 31.02		16 S 32.06		17 Cl 35.46				18 A 39.94	8
4	19 K 39.10		20 Ca 40.68		21 Sc 45.10		22 Ti 47.90		23 V 50.95		24 Cr 52.01		25 Mn 5.493		26 Fe 55.84	27 Co 58 94	28 Ni 58.69		18
		29 Cu 63.57		30 Zn 65.38		31 Ga 79.72		32 Ge 72.60		33 As 74.93		34 Se 79 2		35 Br 79.92				36 Kr 82.9	
5	37 Rb 85.44		38 Sr 87.63		39 Y 88.92		40 Zr 91.22		41 Cb 93.3		42 Mo 96.0		43 Ma		44 Ru 101.7	45 Rh 102.91	46 Pd 106.7		18
		47 Ag 107.88		48 Cd 112.41		49 In 114.8		50 Sn 118.70		51 Sb 121.76		52 Te 127.5		53 I 126.93				54 Xe 130.2	
6	55 Cs 132.81		56 Ba 137.36		Rare Earths		72 Hf 178.6		73 Ta 181.4		74 W 184.0		75 Re 186.31		76 Os 190.8	77 Ir 193.1	78 Pt 195.23		32
		79 Au 197.2		80 Hg 200 61		81 Tl 204.39		82 Pb 207.22		83 Bi 209.00		84 Po 210.		85 Am ?				86 Rn 222.	
7	87 Va ?		88 Ra 225.97		89 Ac 227.		90 Th 232.12		91 Pa 230.9		92 U 238.14								

RARE EARTHS

57 La 139 90	58 Ce 140 13	59 Pr 140 92	60 Nd 144 27	61 Il 146.	62 Sa 150 43	63 Eu 152 0	64 Gd 157 3
65 Tb 159.2	66 Dy 162 46	67 Ho 163 5	68 Er 167 64	69 Tm 169 4	70 Yb 173.5	71 Lu 175.0	

certain of the elements, and he placed them in a table, which is called the periodic table. In his time the table contained 63 elements.

In this table hydrogen is the first element and uranium is number 92. Elements with similar properties occur at intervals of 8, 18, or 32 as we progress along the table. For example, in column two, sodium (11), potassium (19), rubidium (37), and cesium (55), have similar properties. The last column is

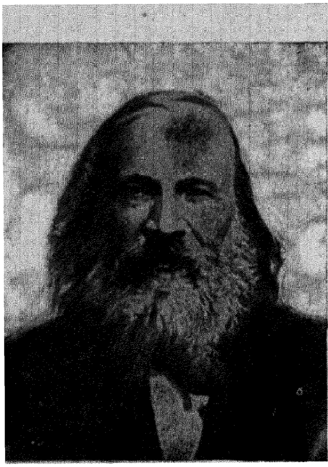

FIG. 101.—Dmitri Mendeleeff (1834–1907). (*From McPherson and Henderson's "First Course in Chemistry," Courtesy Ginn and Company.*)

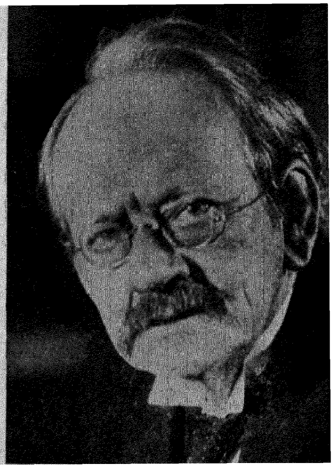

FIG. 102.—J. J. Thomson (1856–). Discoverer of the electron; one of the originators of modern atomic theories. (*Science Service.*)

occupied by the inert gases helium (2), neon (10), argon (18), krypton (36), xenon (54), radon (86) (see p. 211). Study of the table indicates that this interesting similarity applies quite generally. Of the 92 elements, the seven metals, iron, copper, silver, tin, lead, gold, and mercury were known in early times, and were believed to be the only metals possible because of the sacred number seven. One of the 92 elements, number 87, has been only recently reported and named madavium, but the evidence for the discovery is still in dispute. At present, it is believed that the spectroscope (see p. 16) will indicate the existence of element 85

somewhere in the minerals of the earth. With the final discovery of this, the table will be complete.

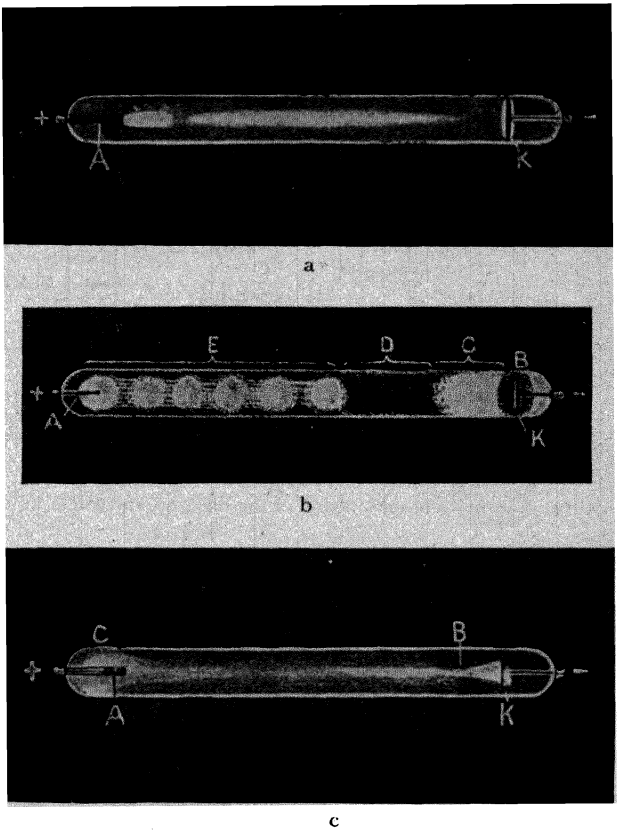

FIG. 103.—Photographs showing the appearance of electrical discharge in air at reduced pressures. (a) At a pressure of a few cm., a glow of light fills the tube. (b) At a pressure of a few millimeters we find a series of colored bands usually of a bright orange shade. (c) When the pressure is reduced to less than .001 millimeter, the color in the tube has almost disappeared and in its place we find that the glass is shining with a yellow fluorescence, due to the impact of the stream of cathode rays (electrons) which are striking the walls. (*From Watson "A Textbook of Physics," Longmans, Green and Co.*)

ATOM MODELS. Up to the beginning of the twentieth century, the atom was believed to resemble an elastic ball with a hard kernel, somewhat like a golf ball. In the period 1895–1897 a

new epoch in the study of atoms was begun. During this period J. J. Thomson (Fig. 102) discovered the electron; Becquerel discovered that uranium was radioactive (emitting rays); and Roentgen discovered X-rays.

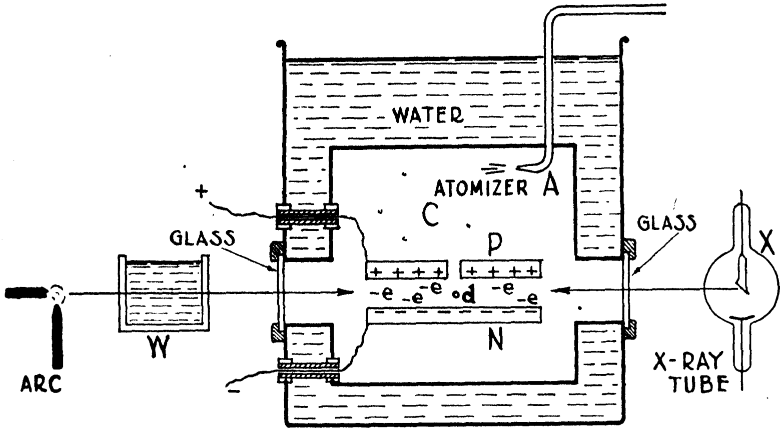

FIG. 104a.—A diagrammatic sketch of the oil-drop apparatus. (*Foley.*)

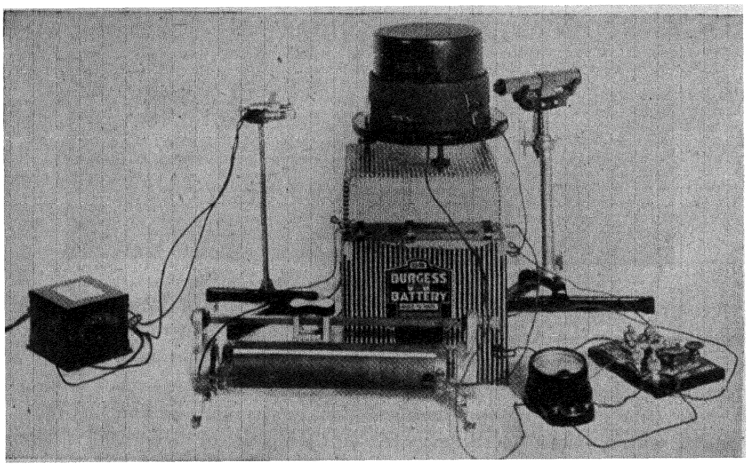

FIG. 104b.—The oil-drop apparatus in operation. (*Central Scientific Company.*)

In the study of the electron, Thomson caused the cathode rays (coming from the negative electrode) to move rapidly through a large evacuated tube (Fig. 103). By the use of a magnet, he

proved that the cathode rays were a stream of negative particles which constituted a current of electricity (see p. 308). Millikan, an American physicist, carried this work forward by the famous oil-drop experiment, receiving the Nobel prize for his work. This experimenter charged small drops of oil by spraying the oil from an atomizer (Fig. 104). These drops were strongly illuminated, and were moved up and down by applying high voltages (see p. 306). By means of this experiment the amount of electricity contained in one electron was determined. (An electron has a charge of 10^{-19} coulombs.)

C. T. R. Wilson passed X-rays into a cloud chamber and photographed the tracks left by the electrons as they moved through a fog. Figures 105–106 illustrate a laboratory form of the apparatus.

At first, it was believed that electrons were small divisions of an atom with electrical charges on their surfaces. After much experimentation, we have come to believe that an *electron is a particle of negative electricity.* The atom seems to contain also a *positive particle*, the *proton*, which is 1835 times as heavy as the electron. These two units, with perhaps the addition of a *neutron* (a particle having weight but no charge), are believed to be constituents of every element in nature. Unfortunately, these statements are rather obscure inasmuch as we do not know the exact nature of electrical particles. Nevertheless, with the discovery of the electron, it became evident that the atom was not the simple "chunk" of matter that scientists had believed it to be.

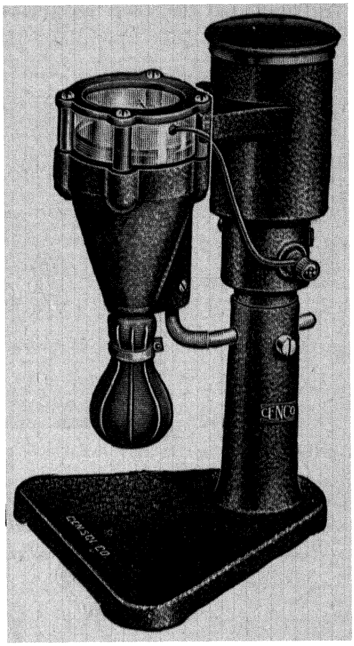

FIG. 105.—A cloud chamber apparatus. When the bulb is pressed and suddenly released a cloud fills the glass chamber. A small piece of polonium in the chamber emits alpha particles which show tracks as they move through the fog. Electrons can be used instead of alpha particles. (*Courtesy Central Scientific Company.*)

At present, we believe that an atom is a cluster of positive and negative charges of electricity, some of which may be combined to form neutrons. When we comb our hair on a dry day, the hair, being attracted to the comb, sometimes stands on end. This is due to positive charges of electricity which have been induced on the hair by friction with the comb. If a rubber rod is

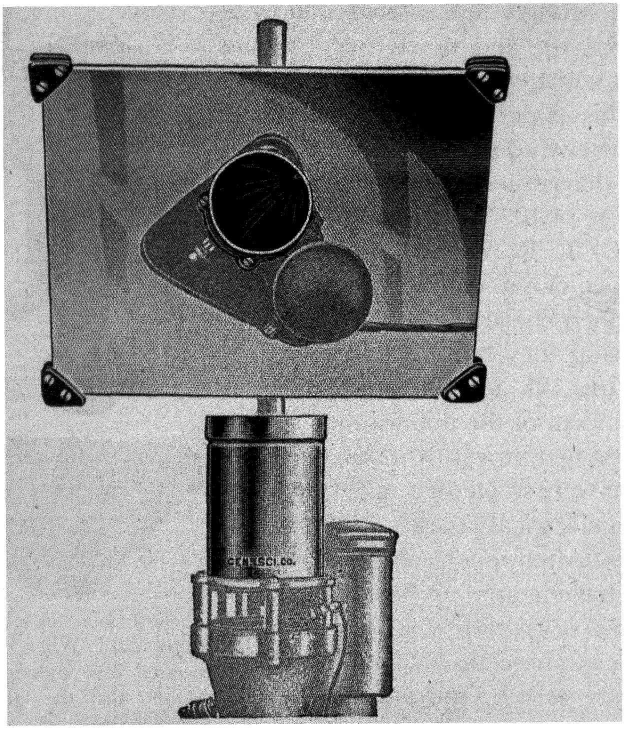

FIG. 106.—The large mirror gives a view of the tracks produced by the alpha particles described in Fig. 105. (*Central Scientific Company.*)

stroked with cat's fur, the rod acquires an excess of electrons and the fur has too few. As one walks across a rug and then touches a metal door knob, a spark is often noticed passing from the hand to the knob. The spark is a current of electricity caused by the electrons passing from the hand to the knob. The various theories of the charges in the atom have given rise to the atom models. *At this point, it must be emphasized that any model is merely an*

attempt to visualize our experimental results. Our familiarity with the electrons may be compared to an acquaintance that we have never seen, but whose voice and habits are familiar. We are prone to form a mental picture of such a person, although it may be far from the correct one. We can see the tracks that the electron makes in a cloud chamber; we find that the electrons are moved by a magnet; we see fluorescence caused by their motion; we can hear the "noise" made by their collisions in a radio tube. By these means we form our mental picture of electron characteristics.

The first electrical model of an atom was devised by Thomson himself. He thought of the atom as a ball of positive electricity, in which the electrons were distributed somewhat like seeds in a pumpkin. This model was abandoned when experiments indicated that the atom contained a small kernel of positive charge, the rest of the atom being practically empty space except for electrons.

Another British scientist, Rutherford (Fig. 107), was the next to try his hand at atom building. He pictured the atom as a tiny solar system, with nucleus and electrons. At the center is the heavy core or nucleus of positive electricity. The electrons revolve about this core somewhat as the planets revolve about the sun. Motion is necessary so that the electrons will not fall into the nucleus, just as revolution of the planets is necessary to preserve the solar system. Like the solar system, the atom is mostly empty space. One electron outside the nucleus, and one proton as a nucleus forms hydrogen. If two electrons surround the core, and if the core contains two protons and two neutrons, the atom is helium. The element, uranium, is believed to contain *92 protons* and *146 neutrons* in the core and *92 electrons* outside the core. Each element is given an atomic number from 1 to 92, which represents the number of electrons surrounding the core. Such a model indicates that every object, including such materials as glass, wood, iron, silver, is composed of electrical charges only! This is a startling statement and one not easily explained.

According to the best evidence the mass of an electron is 9×10^{-28} grams and its diameter is about 10^{-13} cm. The diameter of a proton is about 10^{-16} cm.

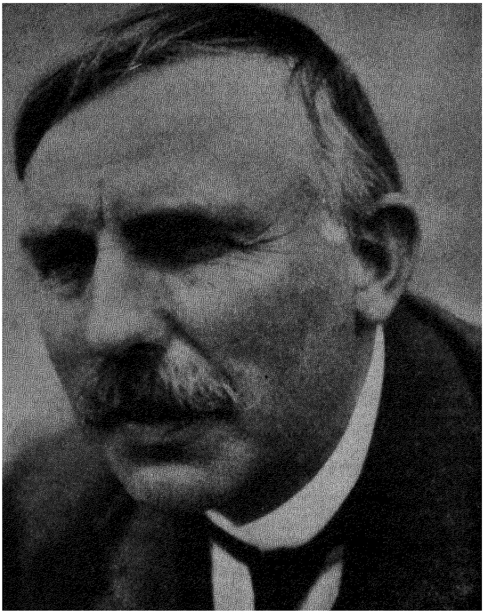

FIG. 107.—Ernest Rutherford (1871–1937). A British physicist; founder of the atom model which bears his name; a researcher in the field of radioactivity. (*Science Service.*)

FIG. 108.—Irving Langmuir (1881–). A brilliant American scientist. He has made many discoveries in the field of vacuum tubes and thin films. His discoveries cover many fields of modern life. (*General Electric Company.*)

If the nucleus were the size of an orange, the electron would be 5000 miles distant. Very small flies in a very large cathedral!

Another interesting model, not the most recent, but one very important in chemical changes, is the *Lewis-Langmuir atom* (Fig. 108). In this theory, devised in 1916, the hydrogen atom is portrayed as having a nucleus and a stationary electron. According to this model, fluorine (atomic number 9) has seven electrons at the corners of a cube, 2 electrons inside the cube, and a nucleus of 9 positive charges. No motion, except vibration, is necessary for this model. When fluorine combines with hydrogen (Fig. 109), the lone electron in the hydrogen atom fits into the vacant corner in the fluorine atom, forming a molecule of hydrogen

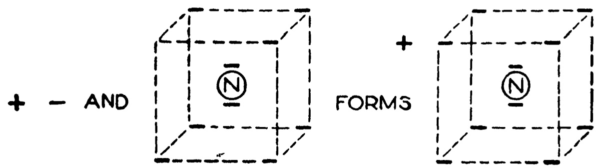

Fig. 109.—Hydrogen combines with fluorine to form hydrogen fluoride. An illustration of the use of the Lewis-Langmuir theory.

fluoride (HF). Similarly, a sodium atom has one electron in its outermost shell. When sodium combines with chlorine, this lone sodium electron fits into a space in the outermost shell of chlorine, forming a molecule of sodium chloride. In a sense, the electron binds the two atoms together. The theory also states that when hydrogen fluoride is dissolved in water, the hydrogen nucleus may split away from its electron, thus making the hydrogen positively charged. The fluorine has a negative charge. These are called ions (see p. 356).

From what has been said up to this point, the reader may feel that our knowledge of the atom is still very deficient. This is certainly true. It is indeed surprising that we have made any progress whatever, when we realize that there are only a few instruments that help us reveal the secrets of the atom. We know that the atoms of a tungsten filament emit white light when the filament is heated. In the spectroscope, this light becomes a

continuous spectrum (rainbow). If a current of electricity is passed through a tube containing neon gas (see p. 17), the neon atoms emit light of a type which the spectroscope separates into a *line* spectrum. When the molecules of a compound such as carbon dioxide are caused to emit light, a *band* spectrum is formed. Under the proper conditions, as we shall see presently, atoms also emit gamma rays, X-rays, ultra-violet, heat rays, and electric radiations. All of these emissions of energy are called radiations. From a study of these radiations, we gain our knowledge of the structure of the atoms which emit the energy.

ENERGY. We are conscious of an entity about us which we call energy (see p. 217). We are warmed by the sun; we read by electric light; we hear by the energy of sound; the energy contained in food furnishes us with the ability to carry on our work. Man has always wondered how the energies of light and heat reach us from the sun. Perhaps the following illustration will be helpful in considering this problem. If a friend were asleep in a boat out on a lake and we, standing on the shore, wished to attract his attention, we could think of several ways of making our presence known. We might call, thus sending sound waves through the air, or we might drop a stone into the water so that the spreading waves would lap against the boat. We might also throw a stone against the boat. A little thought shows us that these various methods really consist of two types; transmitting waves through some medium, or shooting objects through space. In considering the methods by which the various radiations are transmitted from one point to another, the scientist must consider only these two types unless he can discover others.

WAVES. In order to explain the origin and progress of waves, we can use as an example the bobbing of a top connected to a fish line (Fig. 110). Each time the top moves up and down, a wave starts out into the water. The number of waves sent out per second (frequency) is determined by the rapidity with which the top is operated. *The frequency is thus determined by the source of the waves.* If a chip is floating on the water, it will be seen to move up and down, yet to remain in the same location. This indicates that the water itself did not move away from the top, but that the

water wave carried energy in all directions. When this wave strikes an obstacle such as the boat, it will give up the energy to the boat in the form of a blow, producing heat or motion or both. The water is the agency or medium which transmits the energy.

Newton thought of light energy as being transmitted by means of corpuscles. Since light casts sharp shadows, the idea of waves of light seemed improbable to him. Because of Newton's prestige, the idea of corpuscles continued to be prevalent until 1801, when Thomas Young, a youth of 26, presented a paper

FIG. 110.—The bobbing of a top in water. Note that a wave is produced in each time the top moves up and down. (*Foley.*)

before the Royal Society in which he offered the theory that light energy traveled in waves.

This paper provoked a great deal of discussion. A classic illustration of the narrowness of some scientists of that day is the criticism of Lord Brougham as reported in the Edinburgh Review. "We now dismiss, for the present, the feeble lucubrations of this author in which we have searched without success for some trace of learning, acuteness, and ingenuity, that might compensate for his evident deficiency in the powers of solid thinking." Despite such criticisms the wave theory was soon accepted as the correct one.

Various difficulties were apparent, especially the necessity of a medium to transmit the waves. The idea of a medium, called *ether*, was introduced. In the interval from 1850 to 1900, scien-

tists devoted a great deal of work to a study of the ether. (The word ether does not refer to the chemical compound of that name.) The substance was supposed to fill the entire universe, penetrating even solid materials and the atoms themselves. Ether was supposed to be a sort of jelly-like substance, so light in weight, that no experiment could detect it. Waves of energy traveled through ether from the sun and stars, much as a wave travels in water or in a rope. When an electric lamp is turned on in the room, it is assumed that the atoms of the filament absorb energy, with the result that the vibrating electrons in the atoms send out waves in the ether to our eyes. The energy in these waves excites the retina of the eyeball, giving us the sensation of light. Today, we doubt the existence of the ether as an actual material, but we still think of *waves in space*. Because of the greater ease of explanation, we shall continue to discuss the various forms of electromagnetic radiations by the wave method.

Various experiments with *polarized light* (see p. 283) and *interference* seemed to indicate that light certainly was a wave motion. One can readily observe a form of interference, called diffraction, by viewing a bright light through the slit between two nearly closed fingers. A series of fine lines will be noticed in the slit. A single filament lamp is best for the purpose.

QUANTA. Because of the many difficulties with the wave theory, in 1900 Max Planck, a German physicist, proposed a theory that energy was radiated in corpuscles (bullets) called *Quanta*. There were many reasons why such a radical proposal seemed necessary. One of these was the photoelectric effect. It has long been known that if an open arc lamp shines on a polished piece of zinc, electrons are emitted from the zinc surface. Within the last few years, it has been discovered that other metals, notably sodium, potassium, and cesium, have the same property, even when illuminated by ordinary daylight. This discovery has made talking movies possible (see p. 280). We use the photoelectric cell in timing races, opening garage doors by the headlights of the automobile, counting objects, and in operating a host of mechanical devices (Fig. 111).

In the photoelectric effect, the electrons are ejected in such a way that the light seems to have struck the surface in "bullets"

or *Quanta*. In order for the electrons to leave the surface, it is necessary that the light be of the proper color (frequency). Planck assumed that violet light had more energy per quantum than red light, hence it was more effective.

The scientific reader will recognize that we are discussing the equation, Energy equals $h\nu$, where ν is the frequency, and h is the quantum constant 6.5×10^{-27} erg-seconds. This equation has proved to be one of the most valuable of all laws in the entire field of science.

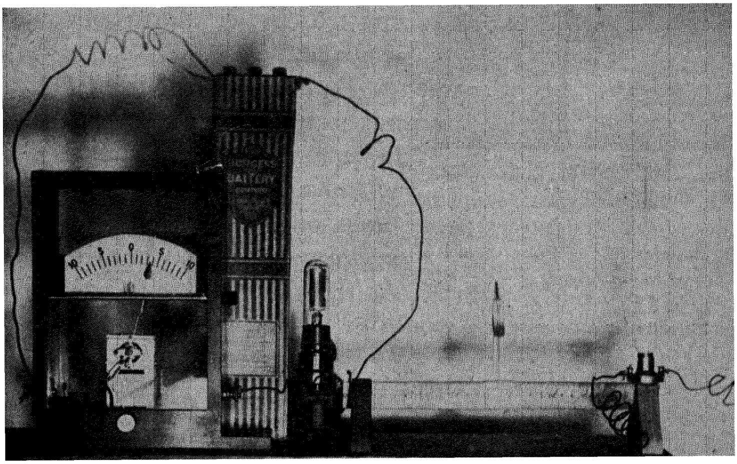

FIG. 111.—A photocell in operation. A light is focused on the cell shown in the center of the figure. A current is produced which operates the galvanometer shown at the left.

The quantum theory placed scientists in a dilemma. Some experiments seemed to prove the existence of waves; other effects seemed to indicate that radiations were corpuscular in nature. In the words of Professor Bragg, "Waves are considered on Monday, Wednesday, and Friday; corpuscles are discussed on Tuesday, Thursday, and Saturday."

BOHR THEORY. It has been the history of science that difficulties give rise to great advances in scientific thought. The quantum theory suggested to Niels Bohr (Fig. 112), a Danish scientist, a remarkable advance in atomic models. In 1913, Bohr, then 28 years of age, adapted the quantum principle to the

Rutherford solar system atom. He advocated the principle that the planetary electrons might revolve about the nucleus only in certain paths without loss of energy. Thus he removed one of the great difficulties of the Rutherford atom. He also assumed that as an electron moved from one orbit to another nearer the nucleus, energy was emitted in the form of quanta (bullets).

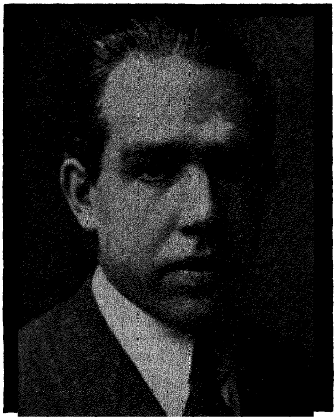

FIG. 112.—Niels Bohr (1885–). A Danish physicist; one of the greatest of modern theoretical physicists; founder of the Bohr theory of the atom. (*Science Service.*)

To illustrate the principle, one might imagine a merry-go-round in which a rider might be permitted to move from an outer seat to an inner one, but he would not be permitted to stand between seats. As the rider moves in toward the center, bullets of energy would be ejected by him.

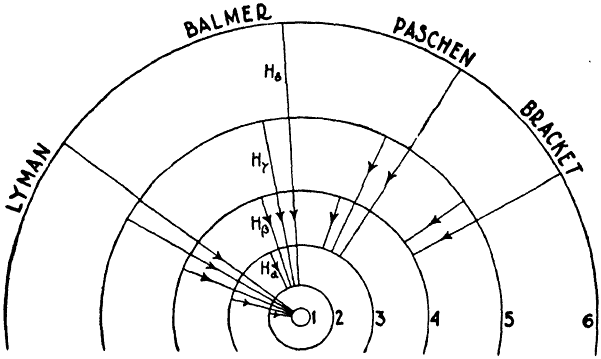

FIG. 113.—The emission of light from a hydrogen atom as portrayed by the Bohr theory. As an electron moves from orbit 3 to orbit 2, there is emitted the red line of hydrogen, one of the Balmer series. The various transfers produce the different lines of the hydrogen spectrum, in the visible, infra-red and ultra-violet. (*Foley.*)

If in Figure 113 the electron of the hydrogen atom moves from orbit 3 to orbit 2, the red line of hydrogen appears. If the electron

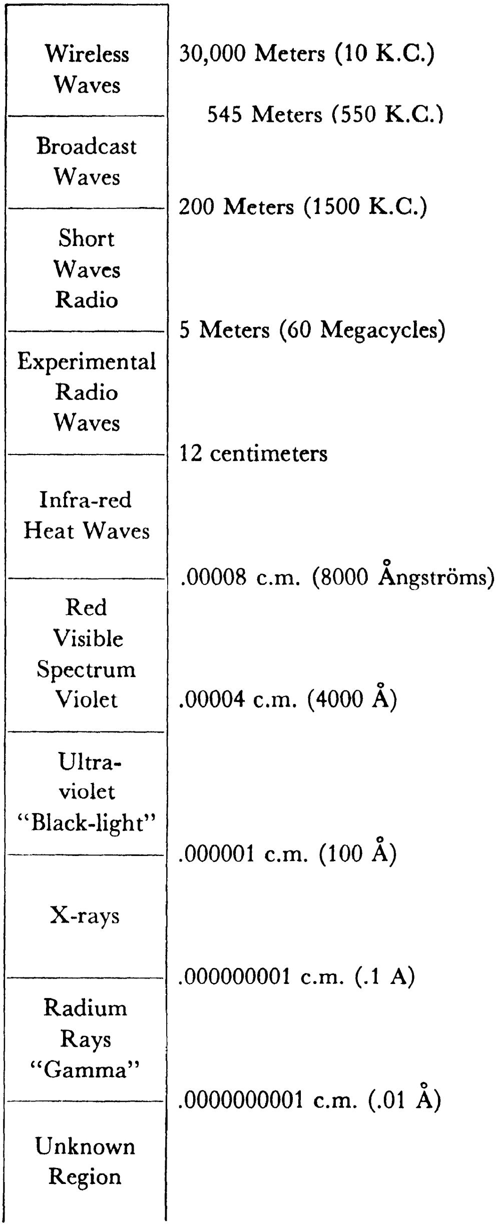

FIG. 114.—The electromagnetic spectrum.

moves from 4 to 2, a blue line appears. If the transfer is from 2 to 1, ultra-violet rays leave the atom.

The theory of Bohr gave an explanation of the line spectra of hydrogen and helium and made possible a satisfactory explanation of the complicated spectra of the other elements. From this time on, the spectroscopic study of atoms made great progress. By improvements in the spectroscope, scientists were able to study electric waves, X-rays, ultra-violet, light, and heat. It was found that all these radiations were of the same character, and they are now grouped under the term electromagnetic radiations (Fig. 114). Each type will be discussed in detail at an appropriate section of the text.

WAVE THEORY. The newest theory of the structure of the atom is the result of the work of Heisenberg, Schrödinger, Dirac, and others. In this atomic model, each individual electron is thought to be somewhat like a gas extending over the entire atom. The positions of the various electrons can be determined only by the laws of chance. Consequently, it is difficult to give a visual representation of the model. Despite this difficulty, this type of structure has been of great importance in interpreting many of the new discoveries in science.

ELECTROMAGNETIC RADIATIONS

The type of wave which any atom will emit depends upon the amount of energy which the atom absorbs and upon the subsequent motion of the electrons. If we could examine the hydrogen in the sun's atmosphere, we would find that some of the atoms were emitting energy in the form of long waves, while other atoms were sending out short-wave energy.

Although all electromagnetic radiations are of the same character, differing only in frequency (vibrations per second), the various radiations are excited in different ways. Radio waves are produced by electrical methods such as those used in broadcasting stations. Bodies at high temperature produce radiations such as heat, light, and ultra-violet. The sudden stopping of electrons moving at high speeds gives rise to X-radiations (Roentgen rays). All of these radiations travel at the same speed in free

space. 186,000 miles per second. There is no sharp dividing line between these various wave lengths, but scientists have arbitrarily divided them into bands, depending upon the method of study of the various types. In the present chapter we shall briefly describe the bands in the order of wave lengths, and we shall reserve a detailed discussion for subsequent chapters.

A wave length is the distance from one wave crest to the next. The *frequency of the wave equals velocity divided by wave length.* The velocity of electromagnetic waves is 3×10^{10} cm. per second. Thus the frequency of a violet spectrum line of mercury is $30{,}000{,}000{,}000/.00004 = 7.5 \times 10^{14}$ vibrations per second.

WIRELESS WAVES. The longest of the waves are the electrical radiations or radio waves. Some waves used vary in length from about 30,000 meters to 550 meters (16 miles to 1/3 mile). Such radiations are sent out by the wireless stations of the world.

The 600 meter wave is reserved for the danger signal (S.O.S.) of shipping. When this wave length is being used, all broadcasting must cease.

The broadcasting band used in North America extends from 545 meters (550 kilocycles) to 199.5 meters (1500 kilocycles). All broadcasting stations are crowded into this band.

(A meter is equal to 39.37 inches, slightly over three feet. An inch is 2.54 cm. A millimeter is 1/25 inch.)

The short-wave band extends from 199.5 meters to 5 meters. Some experimental work has been carried on at a wave length of 1 centimeter.

INFRA-RED. When materials are heated to a high temperature as in a flame, heat energy called *infra-red* is emitted. These waves, ranging from one millimeter down to .001 millimeter, are the waves which upon striking an object may be absorbed, giving up their energy and producing heat in the object.

LIGHT. The next band of radiations, called light or visible light, is the energy that affects the retina of the eye, and the emulsion of photographic plates. It also helps in the growth of plants (see p. 385). These waves vary in length from 8000 to 4000 Ångströms, that is, from extreme red to extreme violet. The entire band constitutes the continuous visible spectrum.

An Ångström is a length unit named after the Swedish scientist of that name. It is 10^{-7} millimeters (one ten-millionth of a millimeter). This means that 8000 Ångströms are equivalent to .0008 millimeters or about .00003 inch.

ULTRA-VIOLET. Beyond the violet lies the invisible region of the ultra-violet which extends from 4000 to 100 Ångströms. These radiations affect a photographic plate and some of them produce fluorescence in minerals.

X-RAYS. X-rays are produced when electrons, which are traveling at a high rate of speed, strike a target made of a metal of high atomic weight, such as platinum or tungsten. These rays are invisible, but have great penetrating power (Chapter 14).

GAMMA RAYS. The shortest wave in the electromagnetic spectrum is the gamma ray emitted by radium and associated elements (gamma is simply a Greek letter and has no significance except to designate the type of ray). This radiation will also be discussed in Chapter 14.

THE NUCLEUS

Having gained some insight into the outer part of the atom, scientists began to consider the nucleus. It had been known since the discovery of the principle of radioactivity* that radium and associated elements were giving out energy from the nucleus or core of the atom. It was realized that the outburst of energy from the nucleus could not be controlled by any known means.

Within the last five years, scientists have learned how to produce "bullets" which have sufficient velocity to shatter nuclei. One such source is the neutron gun, constructed of a mixture of beryllium and radon. Another device is the cyclotron (Fig. 127) of which there are several in operation. This latter instrument gives very high speeds to helium ions, protons, deuterons (ions of heavy hydrogen) and shoots them against atoms. In Chapter 14 some interesting results of this modern "warfare" will be discussed.

* The word radioactivity has no connection with the word radio as used by broadcasting stations.

When one views the marvelous results of modern experimentation and tries to imagine the possibilities of the future, he feels as Newton did when he said, "I seem to have been only like a boy playing on the seashore and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me."

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PROBLEMS

1. Describe three atom models.
2. What is meant by an ultra-violet ray?
3. What does gamma ray mean?
4. What is the Brownian motion?
5. Who was Bohr?
6. Who was Roentgen?
7. What is meant by the quantum theory?
8. How does energy reach us from the sun?
9. What is the nucleus of an atom?
10. Describe the periodic table.
11. Why can we sometimes draw sparks when rubbing a cat?
12. What is an electromagnetic wave?
13. A light wave of wave length 5000 Ångströms has what frequency?
14. A 600 meter radio wave has what frequency?
15. What is a cyclotron?
16. Sketch a model of a chlorine atom.

TOPICS

Quantum Theory.
Radium.
Cosmic Rays.
The Ether.
The Cyclotron.
Neutrons.
The Wave Atom.

VISUAL AIDS

ELECTRONS—University of Chicago Film.

ENERGY AND ITS TRANSFORMATIONS—University of Chicago Film.

CATHODE RAY TUBE—General Electric Co.

EXPERIMENTS

1. It is possible to demonstrate the various radiations described in the chapter. For electric waves one can use one of the wave sets manufactured by the instrument companies. A neon light is used as a receiver so that the entire class can study the reception.

For the demonstration of heat waves, photograph a hot iron in a totally dark room, using the new infra-red film.

The visible spectrum can be shown by the spectroscope. For the ultra-violet, use an argon lamp to show fluorescence of rocks.

Visit the local hospital for an X-ray demonstration.

Any large hospital will furnish radon seeds for a study of radioactivity.

2. Study the Brownian motion as described in the chapter.

3. Study cathode rays. There are oscilloscopes on the market which are inexpensive, and are quite suitable for this purpose.

14

X-RAYS AND RADIOACTIVITY

"The Scientist is a questioner, a discoverer, a pointer-out."
Robinson

ONE OF the wonders of science is the frequency with which some rather obscure laboratory discovery becomes of great commercial and scientific importance. For many years previous

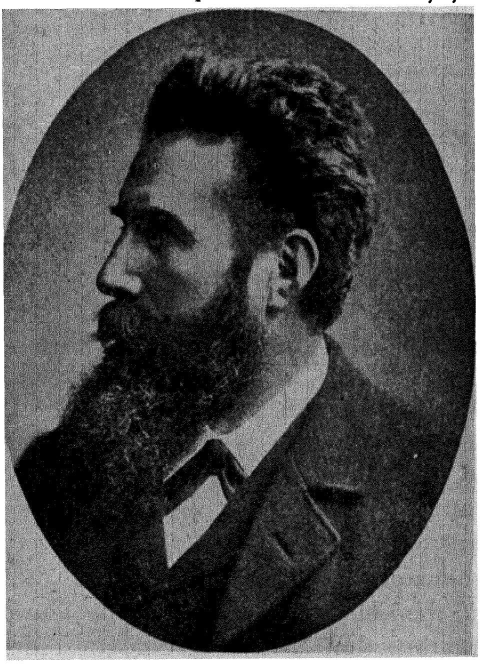

FIG. 115.—Wilhelm Konrad Roentgen (1845–1923). A German physicist; the discoverer of X-rays.

to the discovery of X-rays, laboratories in all parts of the world has been using Crookes tubes to demonstrate the marvelous effects of cathode rays (beams of electrons). Crookes tubes were first designed by Sir William Crookes. These are exhausted tubes having two electrodes. They are made in many peculiar shapes

and give spectacular colors when a high voltage battery is connected to the electrodes.

Up to the time of Roentgen's (Fig. 115) discovery in 1895, no one had ever happened upon the fact that an invisible ray coming from some of the tubes was capable of fogging photographic plates which were wrapped in black paper. With the discovery of X-rays (Roentgen rays) it was soon discovered that these rays passing through the hand or foot, would leave a shadow of the bones on a photographic plate, in much the same manner that the sun casts a shadow of a tree on the ground. Medicine and surgery had been advancing rapidly after the discovery of antiseptics and of

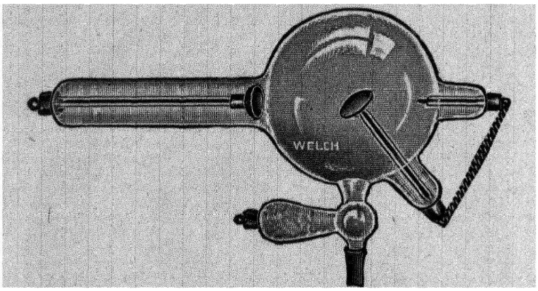

FIG. 116.—An early form of X-ray tube. (*Courtesy Welch Manufacturing Co.*)

anesthesia. Yet the medical specialists were still compelled to guess at many body ailments, often being compelled to operate in an attempt to discover the real difficulty. With the coming of X-rays, the surgeon could take a shadow picture and in many cases determine exactly the proper procedure necessary.

It is significant that the discovery of radioactivity by Becquerel and the isolation of radium by the Curies came at almost the same time that X-rays were discovered by Roentgen. These two great discoveries, X-rays and radioactivity, working hand in hand, are valuable not only in the sciences of medicine and surgery, but also in the fields of chemistry and physics.

X-RAY TUBES AND APPARATUS

An early type of X-ray tube was a crude device consisting of a curved aluminum plate (*cathode*) and a plate of platinum

(*anode*) enclosed in an evacuated glass bulb (Fig. 116). X-rays were emitted from the platinum plate when a high voltage source (20,000 to 60,000 volts) was connected to the two terminals, the platinum being positive. These tubes were very

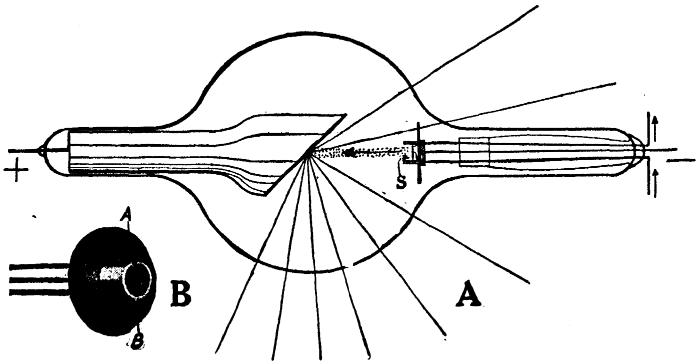

FIG. 117.—(A) Diagram of Coolidge X-ray tube; (B) cathode, showing spiral of tungsten wire.

unsteady; it was difficult to maintain the proper vacuum; and, because of the variety of rays emitted, they were dangerous to the operator. Many of the early experimenters received burns by continued exposure to the rays, which developed into necrosis.

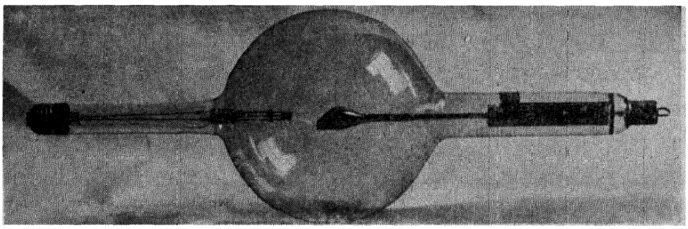

FIG. 118.—The Coolidge X-ray tube. (*Courtesy General Electric Company.*)

X-rays are believed to be a band of electromagnetic waves. The very short waves (hard rays) having a wave length of about .1 Ångström (10^{-8} mm.), are very penetrating, but do not harm tissue as much as the longer waves of about 2 Ångströms. These latter rays are called "soft" X-rays. In 1912, Coolidge of the General Electric company replaced the curved cathode by a

tungsten wire (Fig. 117). The tube was exhausted to the highest possible vacuum, and the filament when heated emitted electrons which were caused to move to the anode (target) by a high voltage source (about 60,000 volts). With this type of tube (Fig. 118) it was possible to adjust the conditions so that only certain wave length bands would be sent out. Moreover, it has been found that lead glass shields around the tube can be used for protection against burns.

The nature of the continuous radiation (white rays) emitted is determined by the voltage applied to the tube. The relation is a direct application of the quantum theory. eV equals $h\nu$ where e is the charge on the electron, V is the applied potential, h is the quantum constant and ν is the frequency of the radiation. If one wishes to produce hard radiation it is necessary to apply a high voltage to the tube. The simple relation between wave length in Ångströms and applied voltage can be stated as follows: wave length $= \frac{12{,}345}{\text{volts}}$.

NATURE OF X-RAYS. For many years the nature of X-rays was in dispute. At present, it is generally believed that the electrons leave the heated filament and move with a speed of about 10^{10} cm. per second (nearly that of light) toward the high voltage anode. Upon striking the target, some of the electrons penetrate far into the atoms of the metal. Because of their great energy, they are able to eject one or more electrons from the inner shells of the atoms. As a result, other electrons drop into these inner shells with the result, according to Bohr's theory of atomic structure, that quanta of great energy, which we call X-rays, are ejected.

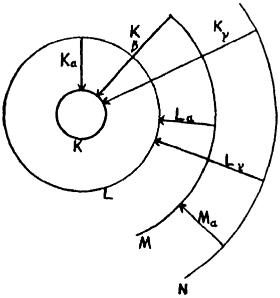

FIG 119.—A sketch illustrating the production of characteristic X-rays

Since the frequency depends upon the energy of a quantum we have very high frequency radiations. These radiations have a very short wave length, far below the range of the human eye. They do, however, affect a photographic plate as does light.

Perhaps the reader is confused by the fact that we mix the terminology of the quantum theory and the wave theory. It is

unfortunate that this is done. As yet, we do not have a sufficiently clear picture to enable us to express our ideas clearly in either the quantum theory or the wave theory. At present, we speak of the frequency of a quantum, and we discuss the frequency of a wave. This is due to our ignorance of the true nature of quanta. Much investigation is being conducted in attempt to understand the difference between waves and quanta.

Under certain conditions we can produce X-ray line spectra called characteristic X-rays. As an example of the method by which an atom produces X-ray spectra, let us consider a tungsten atom (Fig. 119). The innermost ring (K) contains two electrons, the next shell (L) has eight. (We use ring and shell interchangeably, and the writer has purposely used both terms in the same connection.) If an electron is ejected from the K ring, we get the hardest X-rays (K radiations) when another electron enters the vacated space. If an electron is ejected from the L rings, we have L radiations. Naturally, we may have both types at the same time. These radiations are like the line spectra discussed in Chapter 2.

X-RAYS IN SCIENCE. In the previous chapter it was stated that we could not see an atom by means of a microscope because the type of light gave an insufficient resolving power. As the wave length of the light is decreased, the resolving power increases. In 1914, von Laue and his students Friedrich and Knipping, discovered that X-rays could be used in atom study. A narrow beam of X-rays passed through a crystal of the material to be studied. The scattered X-rays then fell on a photographic plate. Figure 120 is the negative secured by passing a beam of X-rays through a crystal of calcite (calcium carbonate). The scattered spots are distributed in such a way that the arrangement of the atoms in the crystal can be studied. By this means, it is possible to study the atomic arrangements in the minerals. Somewhat later, Bragg discovered that a crystal could be used as a diffraction grating to study X-ray line spectra.

A diffraction grating replaces the prism in most modern spectroscopes. We shall not attempt a description of the grating in this text. The reader may consult the references.

With modern apparatus, the wave length of X-ray spectrum lines of an element can be measured with almost the accuracy of the line spectra of such an element as neon. The modern X-ray spectrometer is now a common laboratory instrument. All experimentation indicates that there is no essential difference between

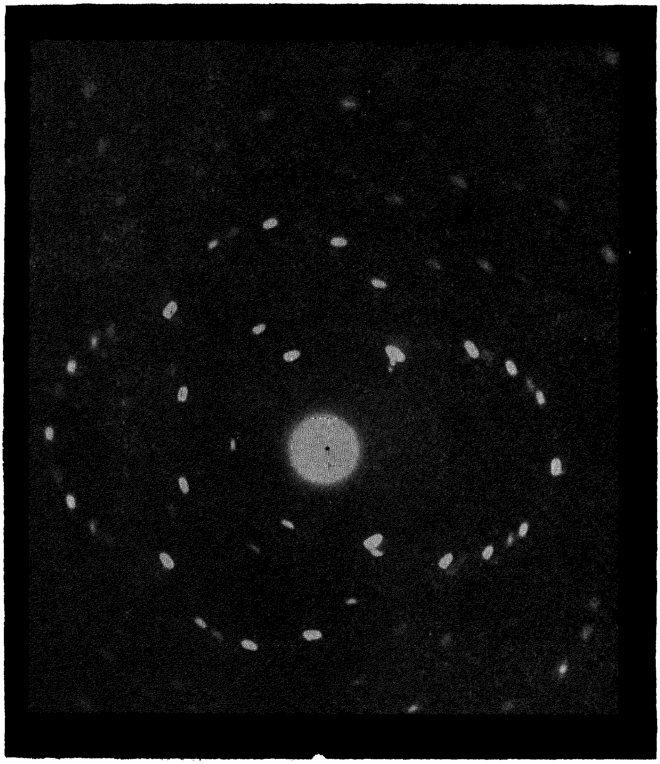

FIG. 120.—A Laue photograph of calcite. The X-ray beam was passed through a crystal of calcite, falling on a photographic plate.

X-rays, light, and ultra-violet. All are electromagnetic radiations differing only in wave length.

In the field of industry, X-rays are used in the detection of hidden flaws in metals; in the examination of the structure of alloys; in a study of electrical insulation; in detecting hidden goods at the custom house; and in verifying the authenticity of old paintings.

X-RAYS IN MEDICINE AND SURGERY

In the hospital, an X-ray examination precedes nearly every operation. In the case of the digestive tract, the patient is given barium sulfate or bismuth carbonate. These materials make the

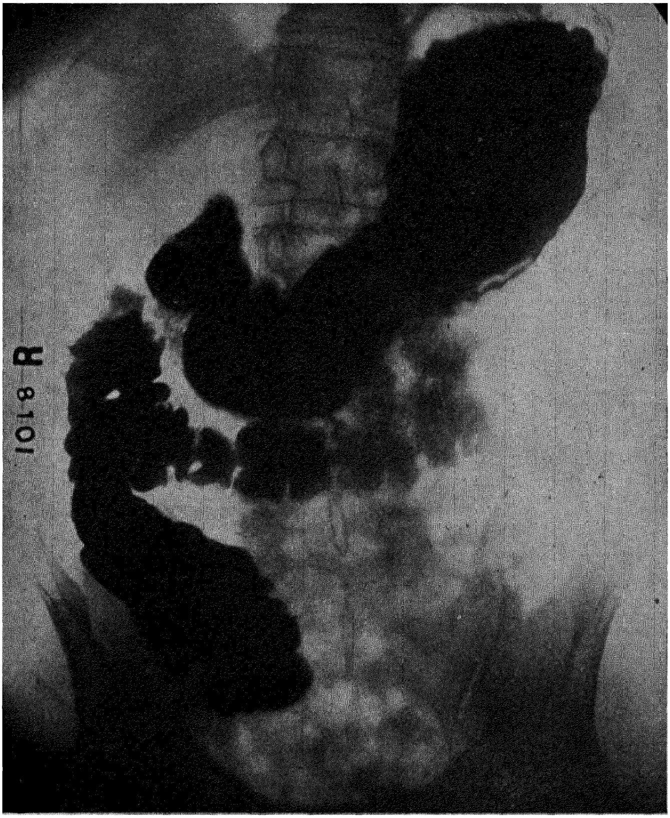

FIG. 121.—An X-ray photograph of the intestines. (*Weld and Palmer.*)

stomach and intestines opaque to X-rays (Fig. 121). Broken bones and dislocations are studied in all parts of the body (Fig. 122). The kidneys, gall bladder, and heart can be studied by injecting materials such as methyl iodide, into the blood. With modern technique, tuberculosis in young children can be detected by a study of lung tissue. By the use of two tubes set at an angle,

stereoscopic depth photographs can be secured, which give the surgeon the exact location of the affected part.

FIG. 122.—X-ray photograph of a broken bone. (*Foley*.)

Some success has also been secured in the destruction of abnormal tissue by X-rays. Such treatment depends upon the interesting fact that normal body cells are more resistant to X-rays than are the cells in malignant growths such as cancer. However, the reason for this is not clearly understood, and the work is still in an experimental stage. Because of the danger involved, such treatments should be undertaken only by experienced operators. To trust oneself to an X-ray treatment by a charlatan is extremely dangerous. It is important so to operate the tube that the patient does not receive an X-ray burn. The burns received from the rays are different from ordinary burns in that they do not heal rapidly, and many have resulted in necrosis. Apparently, in such burns, the recuperative power of the skin has been destroyed.

Recently, X-ray tubes which operate at nearly one million volts have been installed at various hospitals (Fig. 123). The rays emitted from these tubes resemble the gamma rays from radium. In fact, it is estimated that one of these tubes may be as effective as several grams of radium. No one can foresee the future of these magical rays of invisible light.

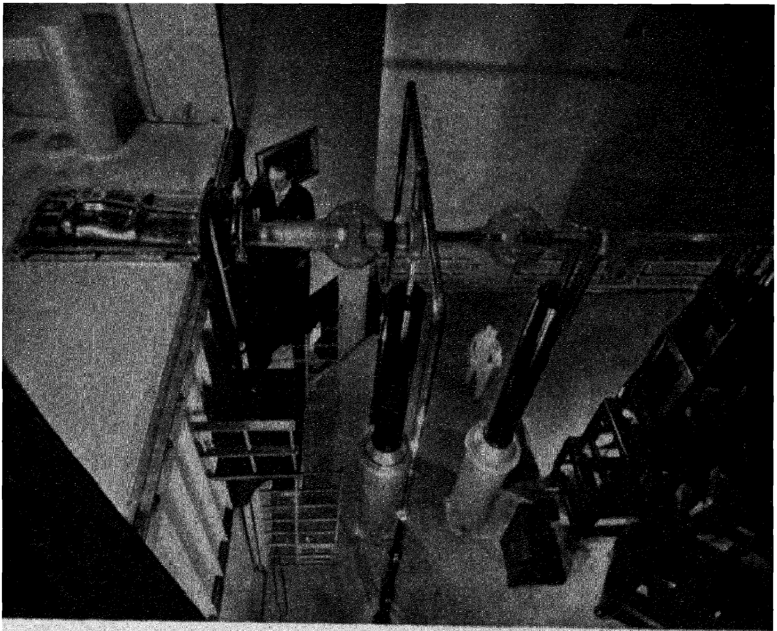

Fig. 123.—800,000 volt X-ray tube. (*Courtesy General Electric Company.*)

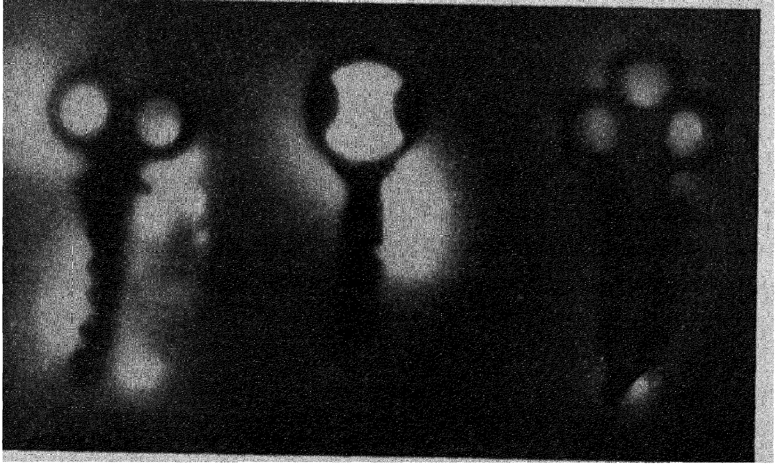

Fig. 124.—Photograph of keys by radium minerals. The keys were placed on the outside of the envelope of the plate and the minerals were laid on the keys. (*Courtesy Dr. E. T. Wherry, University of Pennsylvania.*)

RADIOACTIVITY

At about the same time that Roentgen made his momentous discovery, another scientist, Henri Becquerel, was studying *phosphorescence.*

When some minerals are illuminated with intense light, especially ultraviolet, for a time, they continue to glow after the light has been removed. This is *phosphorescence.* A common example is luminous paint.

One day, it is related, Bequerel placed some uranium ore on a photographic plate which was enclosed in the usual black paper. Imagine his surprise when, a few days later, he found that the plate was fogged as though it had been exposed to weak light (Fig. 124). Becquerel, being too busy to follow up the incident, detailed the task to a young Polish couple, Pierre and Marie Curie (Fig. 125). These people secured a ton of pitchblende (U_3O_8) from Bohemia (pitchblende being a mineral especially rich in uranium ores) and carried on an experiment almost unique in scientific annals. By dint of several years of arduous toil, they separated from the ton of ore a small amount of a salt which showed intense radioactivity. Finally in 1898, the Curies secured a few grains of the two new substances which they called *radium* and *polonium.* These substances were new elements which had startling properties. The compound, radium chloride, looked like table salt but glowed when placed in the dark. The Curies found that the substance produced sores on the skin which were difficult to heal. They also found that one gram of radium would melt its weight of ice each hour. It could destroy bacteria, fog photographic plates even when they were enclosed in sheets of

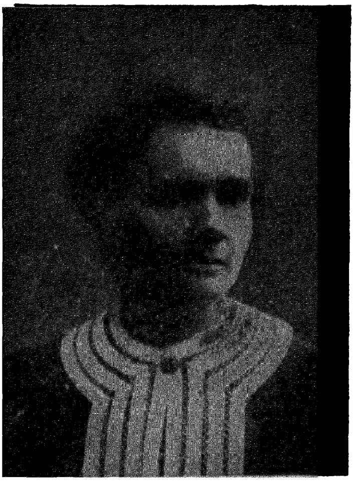

FIG. 125. Marie Curie (1867–1936). Discoverer of radium and investigator of radioactive materials. Nobel Prize winner in 1903. (*Hackh.*)

lead. The material, like X-rays, had the power of killing cancer cells. Today, radium is a necessity in all large hospitals. The only sources of radium are the uranium ores. Up to the present, most of the radium has been produced from ores in the Belgian Congo, but in 1932 prospectors in northern Canada discovered a deposit of pitchblende close to the Arctic Circle. Because of the difficulty of travel in the region, the ores are being transported by airplane to southern Canada. At present, the total supply of refined radium in the world is about two pounds and has a market value of twenty million dollars.

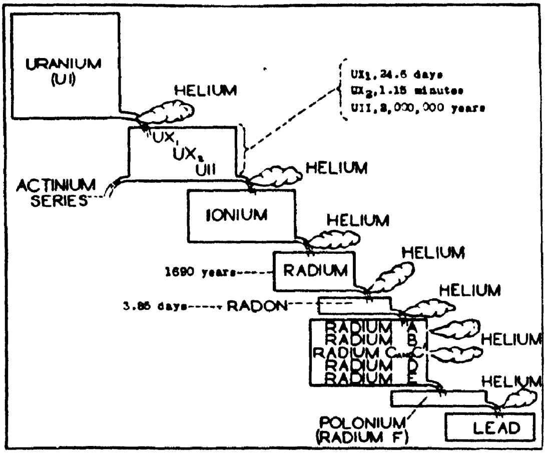

FIG. 126 —The diagram shows the various steps in the transformations of uranium to a form of lead (*Courtesy Scientific American.*)

Rutherford investigated radium and found that, as a result of a long series of radioactive transformations, *uranium atoms change into radium atoms.* Figure 126 illustrates graphically the series of transitions. *Uranium atoms* emit *helium ions* (alpha rays) from the nucleus and change into *ionium*, the process occupying millions of years. *Ionium*, by the ejection of *helium ions*, becomes the element *radium*. An atom of radium has 226 protons and 138 electrons in the nucleus. (According to modern ideas the nucleus of radium consists of 88 protons and 138 neutrons). As the *radium* atom explodes, it in turn ejects a *helium* nucleus and becomes an

atom of *radon* of atomic weight 222. Radon is a chemically inert gas and undergoes transformation rather quickly. The final product of the series of transformations are atoms of *lead* of atomic weight 206.

At some stages in the disintegration, both alpha rays and electrons are emitted. When these particles are shot out, they are usually accompanied by *gamma* rays (short electromagnetic waves of about .04 Ångströms) very similar to X-rays. A gram of radium is changed into radon at such a rate that about one-half of it disappears in 1700 years. These transformations go on continually and the change can be neither retarded nor speeded up by any known means. Each radioactive element has a definite rate of decay and many calculations of the age of the earth have been made by a study of the uranium-radium-lead content of rocks (see p. 78). Perhaps radioactivity may in some way account for the heat of the sun? (See p. 20.)

It has been found that radon is very effective in the treatment of cancer because of its emission of gamma radiation. The gas is pumped out of radium solution and is sealed in tiny gold tubes called seeds. These seeds are implanted in the growth. Although the life of radon is short, its use makes it unnecessary to handle the precious and dangerous radium.

MODERN RADIOACTIVITY

In 1932, Madame Joliot, the daughter of Madame Curie, discovered that if the element *beryllium* were bombarded with *alpha particles* from *radon,* a curious new particle was ejected. This particle was named the *neutron.* It was found to have the same mass as a proton but to have no electrical charge. We may think of it as a *particle having the atomic number zero. If the nucleus of an atom does contain neutrons, we may revise our picture of an atom of uranium as follows: 92 protons and 146 neutrons in the nucleus and 92 electrons outside the core.*

Note. The following discussion can be omitted without loss of continuity. The material is included for the sake of completeness.

In order to better understand the process, a curious new kind of chemical equation has been evolved.

$$Be_4^9 + He_2^4 \rightarrow C_6^{12} + Neutron_0^1 + Energy.$$

In this equation, the lower numbers are atomic numbers and the upper ones atomic weights. One notices with amazement that a combination of *beryllium* with a *helium nucleus* produces the element *carbon* and a *neutron*. Here is *artificial transmutation!** Moreover, the light element, *beryllium*, changes to a heavier element, *carbon*.

Just about this time, it was discovered that ordinary hydrogen contains some hydrogen of mass two (heavy hydrogen). This heavy hydrogen is called *deuterium* and the nucleus is called a *deuteron*. We now have three bullets for our atom gun; a *helium nucleus*, a *proton*, and a *deuteron*. (An electron is too light to be of use in these experiments.)

Within the last three years nuclear disintegration has been carried forward with great enthusiasm. Cockroft and Walton bombarded *lithium* by means of *protons*, forming *helium* with some energy left over.

$$Li_3^7 + H_1^1 \rightarrow He_2^4 + He_2^4 + Energy.$$

Have we here a mass being changed into energy, a thing predicted by Einstein to explain the heat of the sun? It appears that such is the case.

In 1934, the Joliots made the still greater discovery that some of the atoms formed were radioactive! They found that when *magnesium* atoms were bombarded by *helium* ions the result was *radioactive aluminum*.

$$Mg_{12}^{25} \rightarrow He_2^4 + Al_{13}^{28} + H_1^1.$$

Lawrence and Livingston of the University of California have perfected a curious type of atom gun, the *cyclotron* (Fig. 127). In this device, protons and deuterons are whirled around with an ever increasing speed until they attain the speed necessary for nuclear disintegration, whereupon they are shot at the atoms. Bombarding *sodium* with *deuterons*, they found that the sodium was

* Transmutation was the dream of the alchemist.

strongly radioactive, having a useful life of about 24 hours. It appears that the equation for the change is

$$Na_{11}^{23} + H_1^2 \rightarrow Na_{11}^{24} + H_1^1$$

(H_1^2 represents a deuteron.)

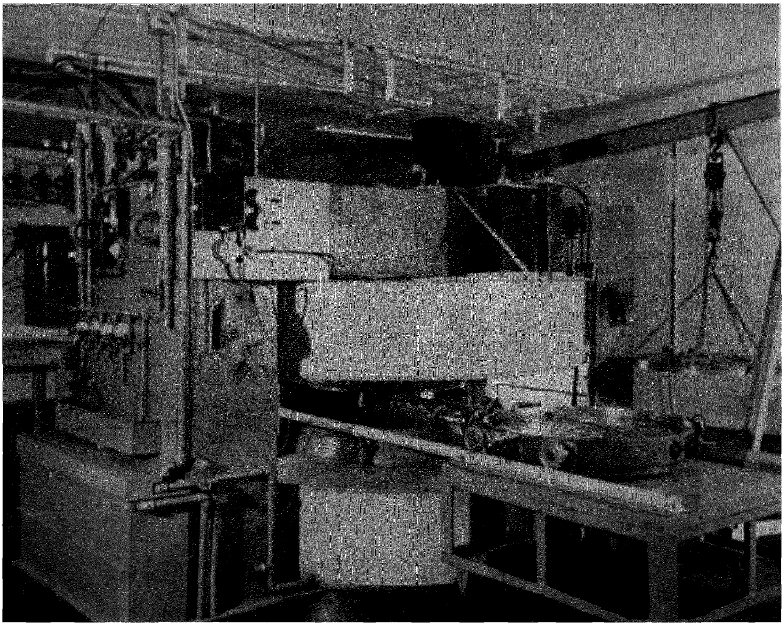

FIG. 127.—The cyclotron. The large flat drums constitute the magnetic field. The flat cylinder on the track is the system from which are emitted the desired rays. (*Courtesy Cancer Research Foundation of the Franklin Institute.*)

The radioactive sodium breaks down as follows:

$$Na_{11}^{24} \rightarrow Mg_{12}^{24} + \text{electron} + \text{gamma ray} + \text{energy}$$

Man can actually produce radioactive atoms at will in the laboratory. At present, about 220 radioactive atoms have been thus prepared. Fermi, an Italian scientist, believes that by this process he has produced an element of atomic number *93*.

COSMIC RAYS

For some years, it has been known that a penetrating radiation of some sort is constantly striking the earth. Its source is

unknown, except that it seems to proceed from interstellar space. At present, most of the rays are believed to be high speed electrons which have great penetrating power. It is too early to make definite statements concerning these mysterious visitors from outside the earth. Some outstanding investigators in this field have been Millikan (Fig. 128) Compton, and Swann.

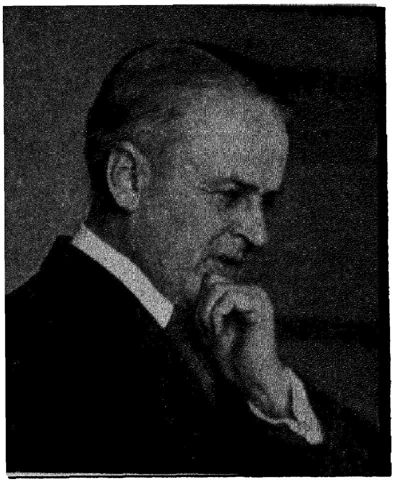

FIG. 128.—Robert Andrews Millikan (1868–). Prominent American physicist; investigator of electrons and cosmic rays. (*Science Service.*)

POSITRON

In 1933, Anderson discovered a new particle which he called the *positron*. It is a particle which has the mass of an electron but consists of positive electricity. Very little is known about the particle.

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PROBLEMS

1. Why can radium be used in the treatment of cancer?
2. How can we study the age of the earth by analyzing radioactive rocks?
3. What is an alpha ray? a gamma ray?
4. Why not use uranium instead of radium?
5. What is artificial radioactivity?
6. Explain clearly the meaning of the term X-ray.
7. What determines the wave length of X-rays?
8. What are cosmic rays?
9. How is radioactive sodium prepared?
10. What precautions are necessary in the use of radium and X-rays?

VISUAL AIDS

RADIOACTIVE RAYS—General Electric Co.
TRANSFORMATIONS OF THE ELEMENTS—General Electric Co.

EXPERIMENTS

1. In a dark room, examine the figures on the dial of a luminous watch or clock. Use a hand lens. The figures will be found to be sparkling by radioactive emission.

2. Cosmic ray apparatus can be secured at small cost from the instrument companies. Study cosmic rays, also gamma rays from radon seeds.

3. Make a photograph of the bones of the hand by an X-ray machine.

4. Place a specimen of the mineral uranite on a covered photographic plate. In a few days the plate will be fogged.

15

ENERGY APPLIED TO MACHINES

"One machine can do the work of fifty ordinary men,
No machine can do the work of one extraordinary man."
Hubbard

WE HAVE already (see p. 190) made use of the term energy in connection with the various radiations emitted by atoms. Energy is always associated with material objects, yet it seems to be unlike them. Absence of energy from objects makes them lifeless, cold, and dead. In the present chapter, we shall describe some forms of energy and their applications to machines. In later chapters, other manifestations of energy will be discussed.

Energy exists in many forms, all of which can be considered as belonging to two fundamental types: *potential energy* (energy of state or position) and *kinetic energy* (energy of motion). We wind a clock spring and the clock acquires potential energy which is released in the form of kinetic energy as the clock keeps time. In operating an automobile, we use gasoline produced by the energy of the sun in past ages. The liquid contains potential energy. When it is passed into the carburetor and exploded in the turning motor, kinetic energy is produced. A storage battery has potential energy which is changed into kinetic energy of electricity when the battery is in use.

If a baseball is thrown into the air, the ball starts upward because of the work done on it by the thrower. The ball moves with decreasing kinetic energy; gains potential energy as it rises until, at the top of its path, all the kinetic energy has become potential energy. The ball falls and the potential energy decreases until at the ground the energy is entirely in the kinetic form.

When food containing potential energy is taken into the body, a chemical change results, which enables the body to per-

form tasks. One of the tasks is that of the heart doing work in pumping blood to all parts of the body. Another task is breathing.

We summarize these effects by saying that the bodies have a form of energy, meaning that *they have the capacity of doing work on either themselves or other bodies.*

It is evident that the constitution of energy has not been explained. We can describe only its effects. It will be further noted that in each of the cases cited, work has been done by some animate or inanimate agency. *Energy can be considered as the cause of work and as the result of work done.* An example of this is the baseball. The thrower does work on the ball, producing energy. When the ball returns to the thrower, it does work on the hand when it is caught.

The potential energy of the baseball is measured by the product of the weight and height. A $\frac{1}{3}$ pound baseball at a height of 30 feet is said to possess 10 foot pounds of potential energy. The kinetic energy of a moving automobile can be calculated by the relation K.E. $= \frac{1}{2}MV^2$, where M is the mass of the car and V is the speed. For example, a 3000 pound car moving at 60 miles per hour (88 feet per second) has a kinetic energy of 11,616,000 foot poundals or 363,000 foot pounds. Because the energy depends upon the square of the speed, a car moving at the speed of 60 miles per hour has 4 times the energy of the same machine moving at 30 miles per hour. This accounts for the great damage in the event of collision at high speeds. The damage done depends not upon the momentum, as is often stated, but upon the kinetic energy.

CONSERVATION OF ENERGY

One of the great principles of science is that of Conservation of Energy. This principle states that the total amount of energy in the universe is constant. (This does not mean that the amount of energy remains constant on the earth.) We may change energy from one form to another, for example, chemical to electrical, but we can never create it or destroy it. On the earth we are constantly giving out energy in the form of light and heat to other parts of the universe, so that the earth actually loses a part

of its store. It may be that we gain from the sun as much as we lose, but it is difficult to prove this statement. Most scientists believe that the earth is actually losing more than it gains, although the amount in the universe is constant. The sources of energy on the earth are our supplies of coal and other fuels (Fig. 129), our water moving in rivers, and the sun's rays. It may be that under special conditions, such as the high temperature of

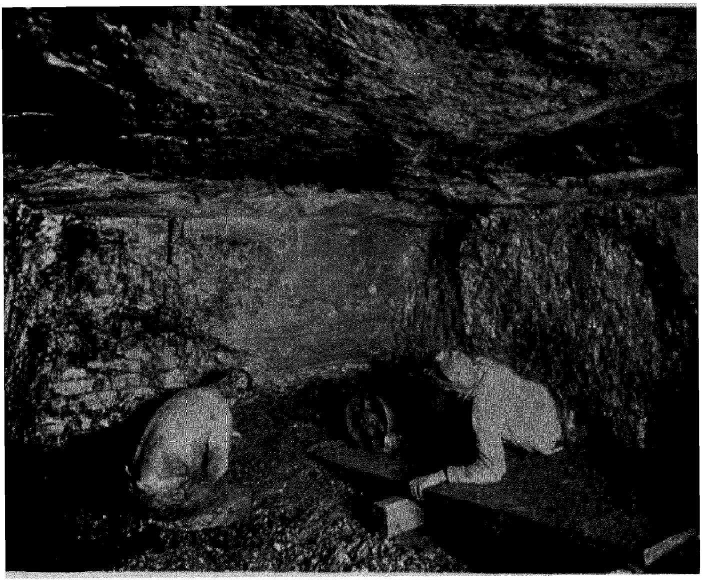

FIG. 129.—Stored sunshine. (*Wendt and Smith.*)

the sun, the principle of conservation of energy may need modification. It was stated in Chapters 2 and 14 that the temperature of the sun is possibly maintained by the creation of energy from matter.

SOME ENERGY VALUES

Potential energy of an alarm clock spring	5 foot pounds
Potential energy of a pound of coal	1,600,000 foot pounds
Potential energy of a pound of steam	160,000 foot pounds
Kinetic energy of a baseball moving at a speed of 45 feet per second	23 foot pounds

Energy Transformations. Some very interesting experiments can be performed to illustrate the transformations of energy from one form to another. The Knipp singing tubes illustrate heat energy being changed into sound energy. The thermocouple (see p. 240) is an example of the change of heat energy into the electrical form. Many chemical reactions, such as thermit, illustrate the relations between chemical energy and light and heat. The simple magneto (Fig. 130) is an example of the transformation of mechanical energy into electrical energy. A swinging pendulum illustrates energy changing from the poten-

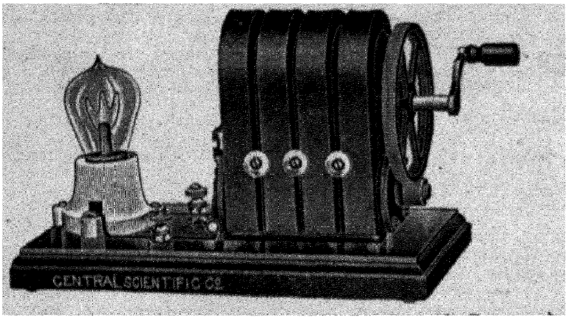

Fig. 130.—The magneto. (*Courtesy Central Scientific Company.*)

tial to the kinetic form. The radio loud speaker is an example of electrical energy being changed into sound.

VELOCITY AND ACCELERATION

This is an age of speed. We travel in automobiles at 60 miles per hour, in trains at 100 miles per hour. Our airplanes sometimes attain the speed of 400 miles per hour, which means that we shall soon be able to cross the continent in a few hours. We have seen that, in an X-ray tube, electrons sometimes have a speed of 100,000 miles per second.

Speed is the rate at which we move, while velocity is speed in a definite direction. If we are driving along a straight road at 30 miles per hour and turn a corner with the speedometer still reading 30, we have changed the velocity but not the speed. We all know that changing the direction sometimes causes skidding. The change of velocity, when the car is turning the corner, brings

into action the inertia of the car which tends to prevent the turn. This tendency is called "centrifugal force."

We wish our automobile to have plenty of "pick up" from a stop and to "get away" in traffic. By this we mean that when we push on the accelerator we wish a quick increase in velocity. This increase is called acceleration. We are frequently accelerating or decelerating our cars. We injure ourselves when we fall from a ladder because our rate of fall increases rapidly and we strike the ground with great force. The force of gravity accelerates the motion of all falling objects. Galileo proved that all falling bodies have the same acceleration, if we neglect air resistance. Newton expressed these ideas in two of his famous laws of motion. He stated that all accelerations are due to forces and, that a body tends to remain either at rest or in uniform velocity unless a force acts upon it. These laws are the basis of most of our mechanical principles.*

FORCE

When one opens a door, lifts a book, claps his hands, utters a word, or steers an automobile, he is exerting a force. Anything which performs what a muscle can accomplish, exerts a force. A force is a push or a pull.

GRAVITATION. One of the outstanding forces in nature is called gravitation. There is exerted everywhere in the universe a force which acts on every material object. This force has the effect of giving all objects on the earth, *weight*. A man who weighs 160 pounds on the earth is pulled to the earth with a force of 160 pounds. If he is in an airplane 5 miles above the surface, he weighs slightly less than 160 pounds. We assume that on the moon the same man would weigh about $\frac{1}{6}$ as much as on the earth. The value of this force is expressed by the law: *the force of gravitation between two bodies depends upon the product of the masses and upon the square of the distance between their centers.* We may write it as an equation,

$$\text{Force} = G\left(\frac{\text{mass}_1 \times \text{mass}_2}{\text{distance}^2}\right), \qquad F = G \times \frac{M_1M_2}{D^2}$$

*The third law states that every action has an equal reaction.

In this equation, the force is expressed in pounds, G is a universal constant, M_1 is the mass of one body, and M_2 the mass of the other in pounds, D is the distance between their centers in feet. (Calculations with this formula lead to some curious results in the stellar universe. A companion star of Sirius in the constellation Canis Major seems to be so dense that a piece of the star the size of a brick would weigh 140,000 pounds.) The weight of an imaginary man on the moon compared to his weight on the earth can be calculated as follows: the radius of the earth is 4 times the radius of the moon; the mass of the moon is $1/90$ of the mass of the earth (these are approximate numbers). We can now write a proportion

$$\frac{160}{\text{weight on moon}} = \frac{90 \times 1}{1 \times 16}$$

Thus his weight on the moon would be about 28 pounds.

The pound is defined as the pull of the earth on a block of platinum kept at London. Since this pull varies as we move about over the earth's surface, it is necessary to state at what point we measure the weight. However, since the difference is small, for ordinary purposes we shall consider the weight of the body to be the same everywhere on the earth.

Another interesting force is the so-called "centrifugal force." We have the centrifugal pump, the centrifugal clothes dryer, the loop-the-loop, the merry-go-round. When the automobile rounds a curve, we lean inward; a skater leans when turning a curve. Skidding of the wheels of an automobile is due to "centrifugal force." Each of these effects illustrates the tendency of a body to continue in a straight line (the law of inertia). In the dryer, the water leaves the clothes whenever the *centripetal* force (force towards the center) is insufficient to keep the drops moving in a circle. A skidding car is simply tending to travel in a straight line. By banking the curve we can overcome this tendency. At the Indianapolis automobile speedway, some of the curves have a bank of 18 degrees (Fig. 131).

THEORY OF GRAVITATION. The law of gravitation was first stated by Newton. Since that time many scientists have tried to

offer some explanation of the mysterious force which controls all bodies in the universe. We believe that the stars themselves are held in place by the attraction of neighboring stars. Up until the time of Einstein, there had been no satisfactory explanation of this curious force which increases as the masses of the bodies increase.

Einstein, as a consequence of his Theory of Relativity (see p. 448) proposed the following revolutionary explanation: Gravitation and accelerated motion are equivalent; they cannot

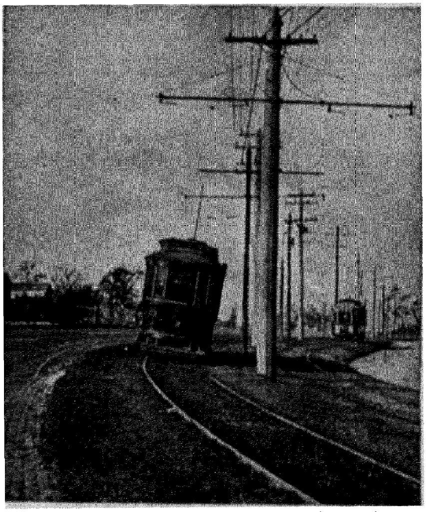

FIG. 131.—A banked curve. (*Foley.*)

be distinguished from each other. In order to make this statement intelligible, we shall use the following examples. Let us imagine ourselves in a closed elevator being hoisted upward with an acceleration of 32 feet per second per second. If an apple is released in the elevator we will rise up to meet it, even if there is no pull of gravity. Since we cannot see out of the elevator, and we are not aware of our motion, we will say that the apple is falling with the acceleration of gravity. In other words, we cannot distinguish the apple falling with the acceleration of gravity from an upward acceleration of the elevator, and the apple at rest.

As another illustration, let us imagine ourselves in a closed box car moving smoothly along a straight track. Suddenly the car rounds a curve and we are thrown to the outside of the car. We may say that someone has tilted the car or we may remark that centripetal force is being exerted on the curve. We cannot distinguish one from the other.

Another consequence of this principle is the equivalence of *mass* and *energy*. As we have stated in Chapter 2, energy equals mass times velocity of light squared, $E = mc^2$. As a consequence, if a mass is annihilated, an equivalent amount of energy is emitted.

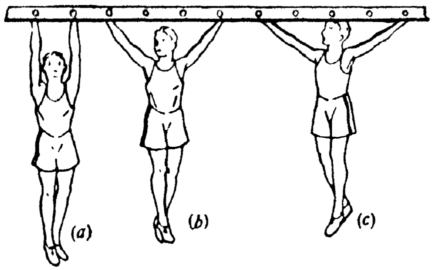

FIG. 132.—Sketch illustrating the forces exerted by the arms at different angles to the vertical. (*From "A First Course in Physics for Colleges," by Millikan, Gale, and Edwards, Ginn and Co.*)

CONCURRENT FORCES. If two forces are acting on a body, the directions of the two effects, either push or pull, must be considered. If a boy grasps a bar with both hands and "chins" himself (Fig. 132), the pull that each arm must exert depends upon the angle between arms. If the arms are vertical, each arm supports one-half of the boy's weight. If the arms make an angle with each other, the pull in each arm must be greater than before, since the arms are to some extent pulling on each other. If the arms are at right angles to each other, the pull in each arm, for a boy weighing 100 pounds, must be about 70 pounds.

One example of such forces is the airplane. (Fig. 133.) Because of the rapid rotation of the propeller, there is a stream of air (wind) pushing against the wing. Part of this air force produces the lift which counteracts the weight (force of gravity) of the plane. Because of the shape of the wing, an additional force is

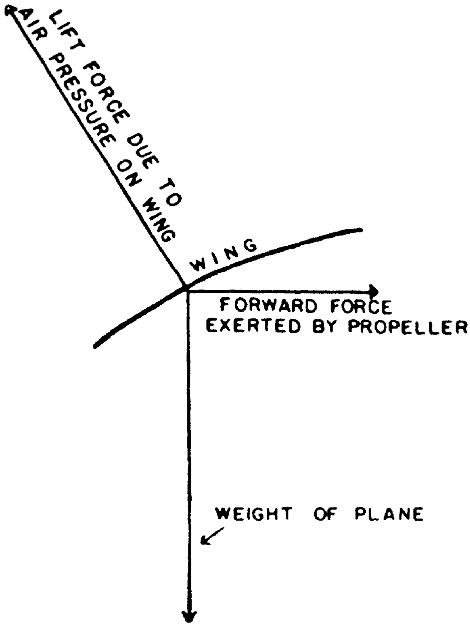

Fig. 133.—Forces on an airplane. (*Hel.*)

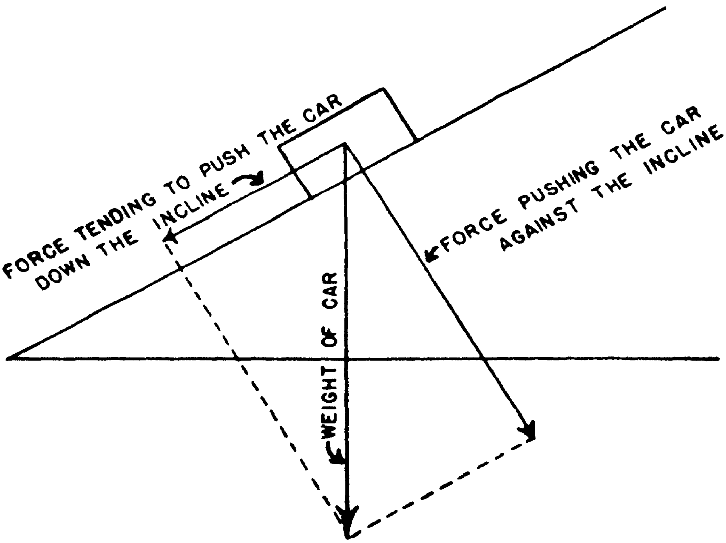

Fig. 134.—A car on the inclined plane. (*Hel.*)

produced which helps to support the plane. The kite is a similar example. The wind blowing against the inclined kite, combined with the pull of the boy, produces a lifting force on the kite.

Every housewife has noticed that a loaded clothesline, if stretched too tightly, may break. The tight rope walker must be certain that his wire is not stretched too tightly, since in such a wire, a 150 pound man may produce a force of a ton or more in the wire.

When a car moves up an incline such as a ramp in a garage, the engine need support only part of the weight since the ramp supports part. This will be clear from the diagram (Fig. 134). The weight of the car acts vertically downward. This weight can be considered as made up of two parts, one force perpendicular and one force parallel to the ramp. The engine, neglecting friction, need only overcome the parallel force in order to pull the car up the slope.

If a 3000 pound car is on a 30 degree slope, the engine must support 1500 pounds. The force perpendicular to the slope is about 2700 pounds. (In this example friction is neglected.)

WORK

Work equals the force times the distance through which the force acts. The force and distance must be in the same direction. Should a 100 pound boy run upstairs to a height of 12 feet, 1200 foot-pounds would be the product of the weight and the vertical distance which he covers. It will be noticed that the same type of example was given for potential energy. As a result of the work, the boy has acquired potential energy. However, if the boy holds a stone in his hand without moving it, he exerts force only. He must move the stone upward to do work. Even if he carries the stone across the room he does no work on the stone, because he is pushing vertically on the stone and at the same time walking in a horizontal direction. The reason for fatigue when holding a weight in the hand, is that we are exerting a muscular effort (a force). But, if the force moves the object vertically, then we can easily calculate the work done. We pay for work done; we hire a

workman to build a house; we pay for energy in our electric light bill; we buy gasoline so that it may do work for us in moving the car.

POWER

In considering the rate at which work is done, we use the term power. Power is the rate of working. *It is not work.* If 55 pounds are lifted 10 feet high each second, the power of the working agency is said to be one Horse Power. One Horse Power is equivalent to 550 foot pounds per second.

It is important to emphasize that in the exact scientific sense, power is not a synonym for force. In popular language, a powerful man means one who can exert great force.

MACHINES

Very early, man discovered that there were certain devices which could be used to aid him in doing his work, principally by making his muscular effort easier. He found that he could roll great stones, fell trees, and overcome other obstacles by their aid. These devices are called machines.

LEVERS. Probably the first machine developed was the lever. The cave man may have discovered that by using a stout limb of a tree, he could pry large boulders out of his path. His fulcrum was probably a small stone or a tree trunk (Fig. 135). The child uses the see-saw (teeter board) and finds that a heavy boy can balance a light one by adjusting the board on the support. Sometimes the children use a third child to secure a balance. The carpenter finds that it is easier to pound a nail if the hammer has a long handle. It is easier to close a door by pushing on the knob than by pushing in the middle of the panel. Other familiar examples of levers are the canoe paddle and the row-boat oar. It must be emphasized that the *machine does not save work.* It makes it possible to do the work more easily. The less the force, the greater the distance through which the force must act, since work equals *force times distance.*

On the see-saw, the lighter boy sits on the longer end of the board, moving up and down through a greater distance than the

heavy boy. An essential part of the lever is the fulcrum, the edge on which the see-saw turns. Archimedes, the famous scientist of Syracuse, said, "Give me whereon I may stand and I will move

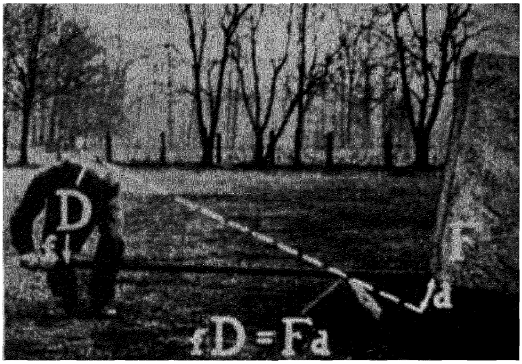

FIG. 135.—The simple first class lever. The effort (f) moving through the distance D raises the load F through the small distance (d). (*Reproduced by permission from the educational sound picture, "Energy and Its Transformations" by H. I. Schlesinger and H. B. Lemon, produced by Erpi Picture Consultants and University of Chicago Press.*)

the world." He meant that if he had a fulcrum outside the earth, a long lever, and a resting place for himself, he could pry the earth out of its position in space.

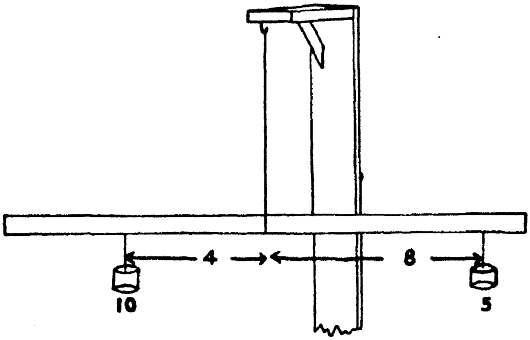

FIG. 136.

A very simple law may be used in making calculations with the lever. In the case of a bar balanced on a fulcrum, and having weights of 5 and 10 pounds on opposite sides at distances of 8 and 4 feet from the fulcrum (Fig. 136), we may write $8 \times 5 = 10 \times 4$,

or force times lever arm equals resistance times lever arm. If (f) is 5 and (F) is 10, (D) is 8 and (d) is 4, then (fD) equals (Fd).

In case there are three forces as in Fig. 137

$$2 \times 10 + 5 \times 8 = 10 \times 6$$

(If the bar is not balanced before the weights are added, the weight of the bar must be considered in the calculations.)

MECHANICAL ADVANTAGE. The mechanical advantage is defined as R/F or the resistance overcome divided by the force applied. By mechanical advantage we mean the saving in force. If, by means of the lever, we can lift two pounds by pushing only

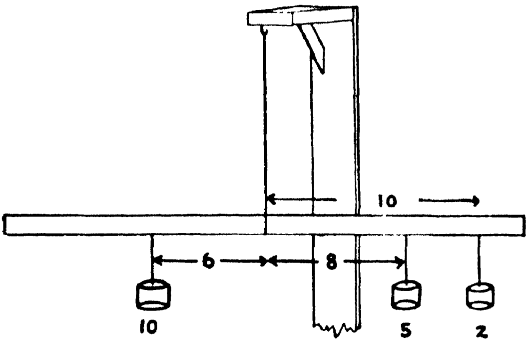

FIG. 137

one pound, the lever has a mechanical advantage of 2. Levers are divided into three classes. The first is exemplified by a pair of shears, the second by a wheelbarrow and the third by sugar tongs or the forearm (Fig. 138).

INCLINED PLANE. Another type of machine is the inclined plane, which we have illustrated by the ramp in a garage. A workman wishing to lift a 300 pound barrel from the ground to a warehouse floor 3 feet high, uses a plank placed one end on the ground and the other on the floor of the building. He may now roll the barrel up the plank by pushing less than 300 pounds. For a plank 15 feet long, he will need to push only 60 pounds. The longer the plank, the less the force he must exert. However, he must push through a longer distance so that he saves himself no work. The ratio of the weight of the barrel to the force applied by

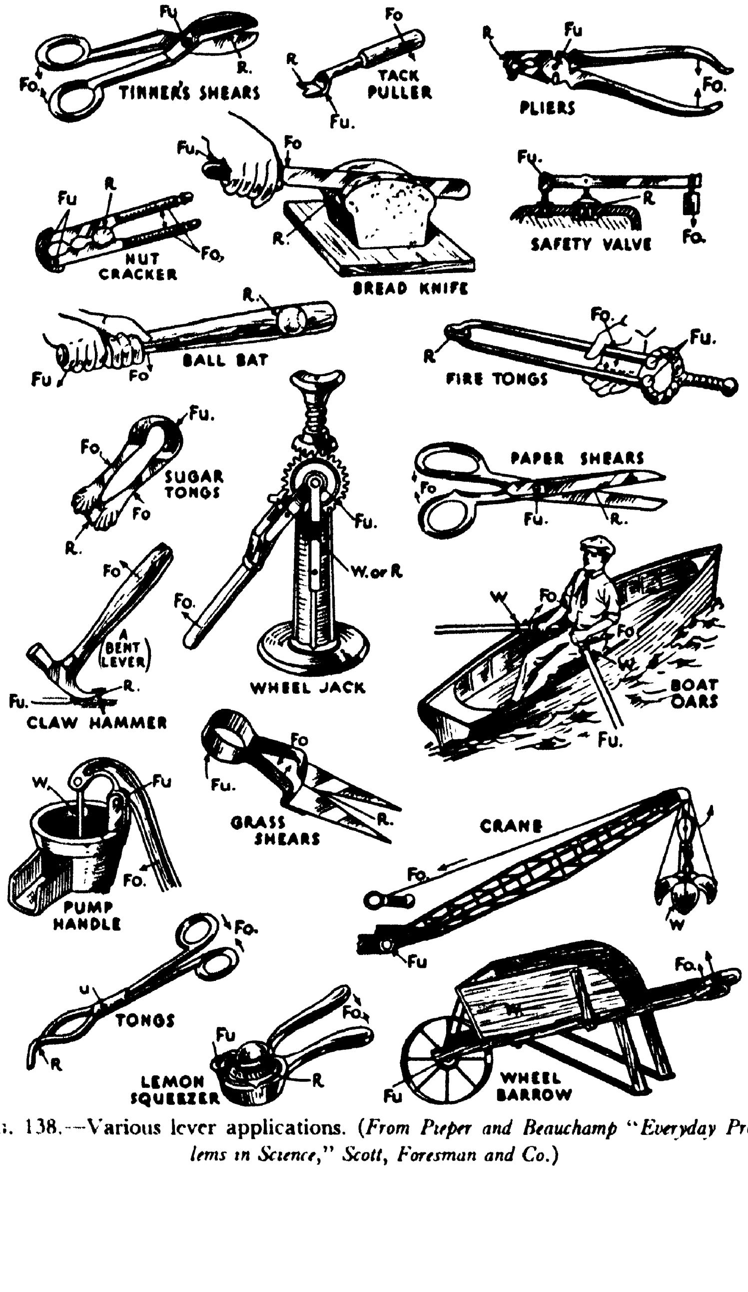

FIG. 138.—Various lever applications. (*From Pieper and Beauchamp "Everyday Problems in Science," Scott, Foresman and Co.*)

the workman is called the mechanical advantage. The law of the inclined plane states that, the weight multiplied by the vertical height equals the force multiplied by the length of the plane (Fig. 139) $WH = FL$. (It must be emphasized, however, that this relation is true only if there is no friction. Since friction is always present, the force exerted in the example will be more than 60 pounds.)

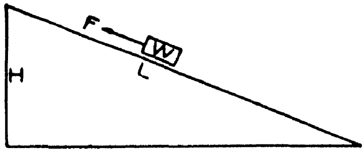

FIG 139.—The inclined plane

In general, the *law of machines states that, neglecting friction, the resistance overcome multiplied by the distance through which the resistance acts equals the effort multiplied by the distance through which the effort is exerted.*

EFFICIENCY. Because of the roughness of the plank, the workman actually does more work (force times distance) on the barrel than he gets out of the operation. The wasted work is used to overcome the resistance due to friction. The *efficiency is the ratio of the work done by the machine to the work put into the machine.* It is a measure of the useful work. No machine is frictionless, and in consequence, the efficiency is always less than 100%. If, for example, the workman uses a force of 100 pounds to roll the 300 pound barrel up the plank of length 15 feet, so that the barrel rises 3 feet, the efficiency equals $\frac{300 \times 3}{100 \times 15}$ or 60%.

A hod carrier carrying bricks up a ladder is an inefficient machine, since he must lift his weight as well as the bricks. A more efficient way would be a pulley system operated by the man on the ground. Some machines, such as the electrical transformer and the steam turbine, have a high efficiency of about 95%, while others such as the wheelbarrow may have only 60% efficiency.

If we could build a perfect machine, we could produce perpetual motion so that a machine once started would move of itself forever. But, since friction is always present, perpetual motion is impossible in a machine. The earth and the other planets of the solar system have almost perpetual motion, because there is practically no frictional resistance to the motion.

From earliest times, man has tried to devise machines which once started would run of themselves. In the past, many patents were issued on such pieces of apparatus, but at present no patent will be granted on such a machine. It will be of interest to the reader to consult the encyclopedia for examples of perpetual motion machines.

FRICTION

Friction is due to the roughness of two surfaces which rub together. At some times friction is desirable. Were it not for friction we could not walk; nails would not hold in wood;

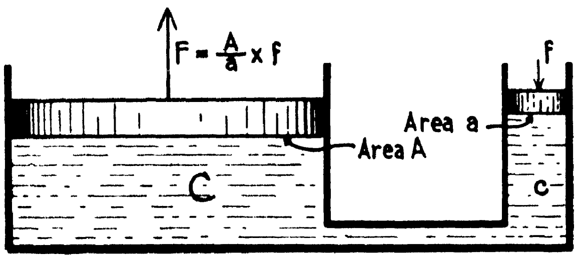

FIG 140. - Model of a hydraulic press The small piston has area a and the large one area A F/f equals A/a (*Foley*)

automobiles could not move. The reason that we slip on smooth ice is because there is too little friction between our shoes and the ice. On the other hand, we are constantly trying to reduce friction in the internal parts of machinery, since friction means low efficiency and causes heat. Because of this, we oil the rubbing parts of motors and other machines.

OTHER TYPES OF MACHINES

Other simple machines in common use are the screw, the wheel and axle, and the pulley. All machines are composed of a few simple ones.

As a familiar example, consider the automobile. As we press the starter our foot is a lever with the heel as the fulcrum. The starting motor turns the engine by a wheel and axle. The engine has a crankshaft which involves a lever. The steering wheel is a wheel and axle. The forearm is a third class lever with the

fulcrum at the elbow. As we drive the car up a ramp in the garage we utilize the inclined plane.

Another type of machine which is in common use is the *hydraulic press* (Fig. 140). It is a familiar sight at service stations, where it is used to raise automobiles for greasing. The machine consists of a large piston which supports the car, and a small piston which moves by the action of compressed air. As the small piston moves up and down many times, it forces oil into the chamber and the large piston rises slowly. The force on the plunger is much less than the weight lifted on the platform of the large piston. The law which applies to this case is

$$\frac{\text{Weight lifted}}{\text{Force applied}} = \frac{\text{Area of large piston}}{\text{Area of small piston}}$$

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PROBLEMS

1. A boy goes fishing, carrying a pole and a one-pound can of beans He catches a fish and wishes to weigh it If he has a foot rule, how can he find the weight?
2. A forearm is one foot long from the elbow to the palm of the hand If a two pound weight is in the hand, what is the pull in the muscles of the forearm, assuming the muscle action to take place 4 inches from the elbow? Answer, 6 pounds.
3. What is meant by conservation of energy?
4. State the law of machines.
5. What is mechanical advantage? What is efficiency?
6. Distinguish between force and work.
7. A workman pushes a 1000 pound weight up a plank 10 feet long. One end of the plank is 2 feet higher than the other He exerts a force of 300 pounds Calculate the mechanical advantage and the efficiency. Answer, $3\frac{1}{3}$; $66\frac{2}{3}\%$.
8. A boy weighing 100 pounds runs up a flight of stairs 20 feet high in 5 seconds. Calculate the work done and the Horse Power exerted. Answers, 2000 foot pounds; .7 Horse Power.

TOPICS

Perpetual Motion.
Efficiency of Machines.
Conservation of Energy.
Automobile Jacks.
Centrifugal Force.
Friction.
Lubrication.

VISUAL AIDS

MACHINES—Eastman Classroom Film.

ENERGY AND ITS TRANSFORMATIONS—University of Chicago Film.

EXPERIMENTS

1. Carefully balance a meter stick in a clamp, noting the position of the knife edge. Place a 100 gram weight at the 60 cm mark and adjust a 50 gram weight until the bar is balanced. Record the distance from the fulcrum to the 50 and 100 gram weights. Check the lever law (Caution If hangers are used, be sure to include their weights.)

2. Place 50 grams at the 80 cm. mark and adjust the 100 gram to secure a balance Check the lever law.

3. Slide the meter stick in its support and clamp it at the 70 cm mark Using only the 100 gram weight, adjust its position until the bar is balanced Calculate the weight of the meter stick (Consider the meter stick weight to be concentrated at the 50 cm. mark Then the meter stick lever arm is 20 cm)

4. Using a stop watch run up a flight of stairs and calculate your work and power. Measure the height of one step and count the steps.

5. If apparatus is available, study some energy transformations Any physics text will give several of the forms which can be easily studied.

6. Make a study of the hydraulic hoist at any service station, or in a barber chair. Determine the load lifted and the force applied to the small piston. If possible, measure the diameters of the two pistons.

16

HEAT, A FORM OF ENERGY

PREVIOUS TO the 19th century, it was generally believed that a body was hot because some sort of a liquid or gas had entered it. This substance called "*caloric*," was believed to have no weight. It was thought that it could be poured into a block of iron making the block hot. In 1798, Rumford, an American scientist, was engaged in military work in Bavaria. He noticed, while boring cannon, that as the boring proceeded the cannon became hot. Being of a scientific turn of mind, he proceeded to test a theory of his, that the heat came from the work which was being done, and not from *caloric*. He tried a dull tool which did not turn out any metal, but the cannon still became hot. Since nothing had entered the metal, he concluded that the operation of rubbing two surfaces together produced heat. Somewhat later Sir Humphrey Davy found that he could melt ice by rubbing two cakes of it together. These experiments finally led men to believe that *heat was a form of energy produced by doing work*. The question was finally settled when Joule (Fig. 141) churned water with a paddle, measuring the amount of *work* (*foot pounds*) done, and the amount of *heat* (*British Thermal Units*) produced. It seems strange to us that the wrong idea of heat

FIG. 141.—James Prescott Joule (1818–1889). This scientist determined the mechanical equivalent of heat; proved experimentally the identity of the various forms of energy. (*Tower, Smith, Turton, and Cope.*)

persisted until such recent times. Unfortunately, wrong ideas are often difficult to eradicate from the minds of people.

Most persons are confused by the words *heat* and *temperature* Temperature is a relative term; boiling water is at a higher temperature than lukewarm water. On the other hand, a tub of lukewarm water, because of its great mass, may contain more heat energy than a tin cup of boiling water. A thermometer measures temperature but does not directly indicate the amount of heat energy in the substance. The coldest temperature recorded on the earth outside a scientific laboratory, is about −80°F. Men have produced solid helium at a temperature of about −450°F. This is within a few degrees of absolute zero (−459°F.).

From a study of certain problems in heat, scientists have come to the conclusion that there is a *lowest* temperature at which point no heat energy exists. We believe that at this *absolute zero* the molecules of substances have no heat energy. They are not in motion. Were we, by means of a flame, to apply heat to a piece of copper at absolute zero, the molecules would take in energy and begin to move to and fro. If the piece of metal were very small, the molecules would absorb the heat rapidly and the temperature would rise quickly. This means that, as a rule, adding heat to a substance also increases the temperature. Exceptions to this are found in the change of state (see p. 242). If we were to use a piece of aluminum of the same mass as the copper, the rise of temperature would be slower. Since we have used the same flame in the two cases, it is evident that the rise in temperature may depend on the composition of the substance under test.

Specific Heat. Similarly if two beakers, one containing 100 grams of water, and the other 100 grams of oil, are heated for the *same length* of *time* over the *same flame*, the oil will be at a much higher temperature than the water. The term *specific heat* designates the effect of heat on the temperature of bodies. Water has the highest specific heat and is used as a standard, all other substances being compared with it. Because of its high specific

heat, boiling water gives very painful burns, since it gives out a great deal of heat to the skin.

TABLE OF SPECIFIC HEATS

Aluminum	.219
Lead	.03
Olive Oil	.47
Water	1.00
Copper	.093
Mercury	.033
Ice	.502
Steam	.47

Thus it is evident that the amount of heat in a body depends upon the *mass*, the *specific heat*, and the *temperature*. Heat is measured in *calories* or in *British Thermal Units*.

A calorie is the amount of heat required to raise the temperature of one gram of water one degree centigrade. A British Thermal Unit is the heat required to raise the temperature of one pound of water one degree Fahrenheit.

TEMPERATURE

Every one has some sense of temperature. This means that we can usually estimate which is the warmer of two objects. If a body is warmer than the hand, it feels warm. If an object is at a lower temperature than the hand, it feels cool. Unfortunately, this sense is not accurate. If a person comes from cold outdoors into a room, he may exclaim that the room is warm, but after he remains for a time, he may begin to complain that the room is cold. Another illustration is a marble or tile floor in a warm room. The marble will feel cold even though it is at the same temperature as the woodwork. It can be seen that touch cannot be depended upon for temperature measurements.

An interesting demonstration is to place thermometers on pieces of copper, granite, and wood. Although the thermometers read the same, the copper and granite will feel much colder than the wood.

In measuring temperature, it is necessary that we use the temperature of some object as a fixed point (starting point).

There must be some temperature that every one will agree upon as a starting point. We might use normal body temperature (98.6°F.) for such a point. However, this temperature varies slightly with different individuals and is not suitable.

It is rather amusing that the most obvious substance, water, was not considered until suggestions of such temperatures as melting butter, temperature of a deer, the temperature of a cellar in Paris, the boiling point of alcohol, had been discarded. It is now agreed to use the temperature of melting ice, and the temperature of water boiling at a barometer pressure of 76 cm. (standard pressure) as fixed points.

TABLE OF STANDARD TEMPERATURES

Substance	*C*	*F*	*Absolute*
Helium (boiling point)	−269	−454	4
Mercury (freezing point)	−38.9	−38	234
Water (freezing point)	0	32	273
Tin (melting point)	232	450	505
Silver (melting point)	960	1760	1233
Tungsten (melting point)	3000	5400	3273
Sun (surface temperature)	6000	10800	6273

THERMOMETERS. Any device which measures temperature is called a thermometer. Until the time of Galileo, thermometers were unknown. It was desired to make an instrument to measure the temperature of fever patients. Galileo's thermometer consisted of a glass bulb with a long stem (Fig. 142). The bulb and part of the stem were filled with air and the remainder of the stem contained water. When the temperature rose because of the body heat, the air in the bulb expanded pushing the water column downward. This was a crude thermometer. The next steps were the sealing of the stem and the use of mercury. Of the many scales that have been invented only two have survived, the Fahrenheit and the Centigrade (Fig. 143).

A mercury thermometer is made by filling the bulb and part of the stem with mercury. The glass is then heated and sealed off.

The bulb is now placed in melting ice and the position of the mercury column marked. For a Fahrenheit thermometer this point is called 32, for a Centigrade it is called zero. The thermometer is now placed in steam over boiling water, and the atmospheric pressure noted by means of a barometer. If the pressure is 76 cm., the thermometer reading is 212°F., and 100°C. The thermometer is then divided into equal divisions; 100 divisions on the Centigrade and 180 on the Fahrenheit. If we wish to find the value of one temperature in terms of the other, we use the relation

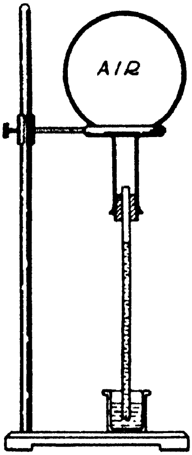


FIG. 142.—Galileo's thermometer. (*Bowden.*)

$$\frac{F - 32}{180} = \frac{C}{100}$$

For example, to find the value of 20°C. in terms of F, we substitute 20 for C., in which case F. is 68.

For ordinary temperatures, mercury is the best liquid since it does not stick to glass. A clinical thermometer is a mercury thermometer that has a constriction in the stem, so that the mercury does not drop back after the bulb is removed from the patient's mouth. This enables the physician to read the thermometer at his leisure.

Oven thermometers are made of pyrex glass, and contain nitrogen above the mercury. One may use such a thermometer up to 700°C. For temperatures below the freezing point of mercury, alcohol is used.

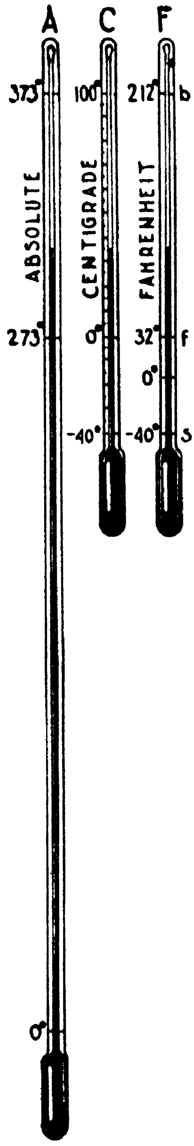


FIG. 143.—Thermometer scales (*Foley.*)

THERMOCOUPLE. For high temperatures we use a device known as a thermocouple. In this device, two wires of different metals, such as copper and iron have their ends fastened together as shown in Fig. 144. A current measuring instrument G is placed in the circuit. If one junction is heated and the other kept cold, an electric current will flow in the circuit. The amount

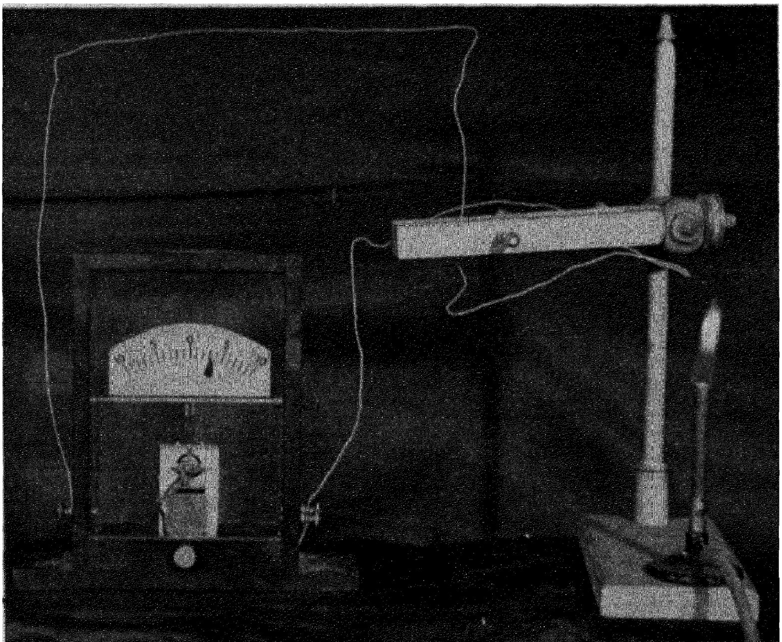


FIG. 144. The thermocouple. Two wires of copper and iron have their ends fastened together to form a junction. When this junction is placed in a flame a current operates the galvanometer.

of this current depends upon the difference in temperature between the two junctions. A thermocouple can be made cheaply, and the observer need not be near the furnace to read the temperature. Since the galvanometer can be placed in an office some distance away, such couples are used in steel furnaces and pottery kilns. A very small couple (.02 inch in diameter), enclosed in a vacuum, is the most sensitive thermometer known. Such an apparatus can be used to measure the temperatures of planets such as Mars.

In measuring the temperature of the sun a pyrometer is used. It is well known that the color of a hot body is a measure of its temperature. Cherry red indicates a temperature of about 500°C., and blue a temperature of several thousand degrees. In the optical pyrometer, a lamp filament is placed in front of the furnace or hot object, and the brightness of the filament adjusted. (There are certain corrections to be made to secure a reading) (Fig. 78b)

EXPANSION

Everyone is familiar with the spaces left for expansion between railroad rails; with the mercury cups in a clock pendulum; and with the thermostat for temperature control. When heat is applied to materials they usually change shape, in most cases they increase in length. We have all noticed a sidewalk buckling on a hot summer day, because of insufficient expansion joints. A concrete road has gaps left between blocks. All large bridges have a very elaborate system of expansion joints which permit the metal to change length without warping the bridge. The rim of the balance wheel of a good watch is so made that it changes shape without causing the watch to gain or lose time. We find that a cheap watch loses time in hot weather.

When boiling water is poured into a thick glass jar, the inside will expand more rapidly than the outside, and the jar may crack. For this reason, chemical glassware is always thin. Some of the newer glasses like pyrex, do not expand much when heated and can be used over a direct flame. If a quartz rod is available, one may demonstrate its low expansion by heating an end of the rod to red heat and plunging it into ice water. The rod will not break.

Expansion of Water. The expansion of water on cooling is a very interesting and unusual process. If we have a jar of water at 20°C. and begin to cool it, the volume will shrink until it reaches 4°C. At this point the volume becomes a minimum (one cubic centimeter weighs one gram) but, if the cooling continues, the volume may increase so rapidly that the pressure breaks the jar. We are all familiar with the bursting of water pipes in cold weather. Nature makes use of this increase in volume with freezing to preserve fish life in lakes and rivers. Because ice is less dense than water, the ice forms at the top of water instead of at

the bottom (a cubic foot of water weighs about 62.5 pounds and a cubic foot of ice about 56 pounds). In deep lakes, the water at the bottom has a temperature of about 4°C. throughout the year.

CHANGE OF STATE

There are three possible states of matter: solid, liquid, and gas. Water is a substance which we know as ice, liquid water, and steam (water vapor). Most substances are known in only two states at ordinary temperature, for example, solid and liquid butter, liquid and gaseous gasoline.

HEAT OF FUSION. The process of changing from one state to the other is very interesting. We shall illustrate by means of water. If we drop a piece of ice into a pan of water and apply heat, we find that the temperature of the mixture remains at zero degrees Centigrade until all the ice has melted. We have applied heat but no change of temperature has resulted. The heat applied to melt the ice is called heat of fusion.

Experiment shows that 80 calories of heat are required to melt a gram of ice without any change of temperature. Apparently, the heat has been used in tearing the molecules apart. The energy is not lost, but is stored as potential energy (see p. 217). When water freezes at zero, the same amount of heat is given off.

An interesting application of this principle is the use of water to prevent vegetables from freezing in the cellar. Most vegetables freeze at about −2°C. If several tubs of water were placed in the cellar and the temperature should drop to zero Centigrade the water would become ice, thereby liberating 80 calories for each gram frozen. The liberated heat would warm the cellar, and protect the vegetables.

Perhaps the most important commercial use of the heat of fusion of ice is the ice box or refrigerator. In the ice box, the cake of ice, in melting, absorbs the heat from the contents of the box, so that they become colder. It is essential that the ice should melt rapidly. Covering the ice with paper or cloth defeats the purpose of the box. Since cold air is more dense than warm air, the ice is placed in the top compartment to produce a circulation which will cool the food.

HEAT OF VAPORIZATION. In the case of the change of state from a liquid to a gas we have a principle similar to heat of fusion. If one gram of water is changed to water vapor at 100°C., 539 calories of heat are required to change the state. This is *heat of vaporization*.

In Chapter 11 it has been stated that molecules of gas are in rapid motion, having kinetic energy due to the temperature. In a liquid, some of the molecules have rather high speeds, while others move more slowly. The high speed molecules may have enough kinetic energy to push through the surface of the liquid and escape. Since the temperature of the liquid is determined by the speed of the molecules, the liquid thus becomes cooler. Everyone has noticed that when alcohol, gasoline, or ether are poured on the hand, the liquid quickly disappears, leaving the hand cold. Fever patients are bathed in alcohol, to remove excess heat from the skin and give relief to the sufferer. The explanation is that the heat of the body has increased the kinetic energy of the molecules of the alcohol, resulting in rapid evaporation which leaves the slower molecules behind.

Everyone has noticed that wet clothes on the body feel cold. In this case, the body heat is being used in causing the evaporation of the water. Woolen bathing suits are more comfortable than cotton because of the slower evaporation from the wool.

A fan cools our skin by causing a circulation of air which removes perspiration. (If the humidity is high, evaporation does not take place rapidly.) Evaporation takes place rapidly from the leaves of trees, and the sap rises in the trunk to replace the loss.

One of Aesop's fables relates that on a cold winter day a wood satyr came upon a half frozen traveller who had lost his way. Taking pity on the man, the satyr went to prepare some broth. Returning with the steaming liquid, he noticed that the half-frozen man was blowing on his hands to warm them. When the traveller was given the broth, he blew on the liquid to cool it. The satyr would not tolerate a man who could blow *hot* and *cold* with the same breath. The explanation is left as an exercise for the student.

Boiling. A boiling liquid is one which is bubbling as it evaporates. When a pan of water is placed on the stove, the temperature of the water rises until the boiling point is reached. As soon as the water begins to bubble vigorously, the temperature remains constant until all of the water has changed into water vapor. Because of this fact, one cannot hasten the cooking of vegetables by boiling the water vigorously. As soon as the water begins to boil, the heat supply should be decreased until it is just sufficient to maintain the boiling temperature. However, the cooking of foods can be hastened by adding salt to the water, thus raising the boiling point.

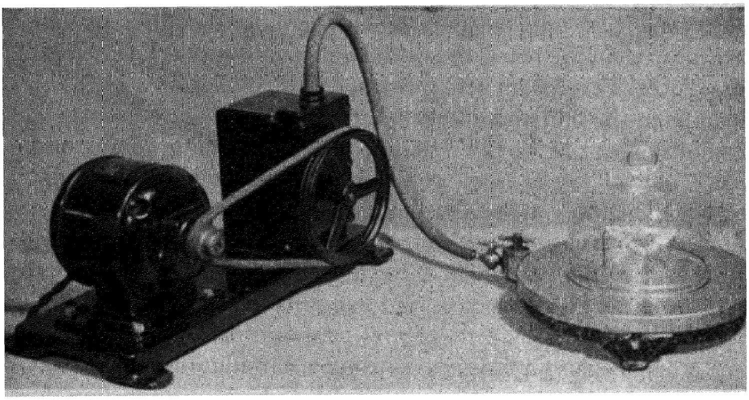


Fig. 145.—Underneath the bell jar is placed a small amount of water and a dish of concentrated sulfuric acid. When the air is exhausted by the pump the water evaporates rapidly and cools. At 32°F. it boils as it freezes.

Water can boil at temperatures from 0°C. up to above one hundred degrees, since its boiling point depends upon the atmospheric pressure above the liquid. For instance, water will boil at 0°C. (32°F.) when the pressure is 4 millimeters, and will boil at 100°C. (212°F.) when the pressure is 760 millimeters (Appendix IV). In order not to burn the syrup, sugar refiners boil the solution at about 50°C. On high mountains, water boils at such a low temperature that food will not cook, making the use of pressure cookers necessary. At an elevation of 14,000

feet (Pikes Peak) the mean boiling temperature is about 86°C. (187°F.)

A very instructive experiment can be performed to illustrate the boiling of water at 0°C. A good air pump is used to exhaust the air from a bell jar in which is placed a small amount of water and a dish of sulphuric acid. The concentrated acid absorbs the water vapor so that ice forms on the boiling water (Fig. 145).

As a demonstration of boiling under reduced pressure, partially fill a *round bottomed* flask with water and boil it. After the water has boiled vigorously remove the flask from the flame and cork it tightly. Invert the flask and pour water over it. The water will resume boiling, because the cold water condenses the water vapor and reduces the pressure inside the flask (Fig. 146).

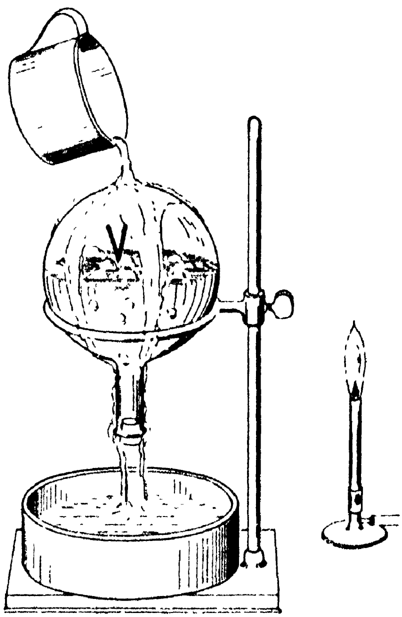


FIG. 146. Boiling under reduced pressure. (*Foley*.)

REFRIGERATION

DRY ICE. One of the interesting applications of evaporation is the production of solid carbon dioxide (dry ice). Tanks of carbon dioxide, such as are used at soda fountains, contain a mixture of liquid and vapor. If such a tank is placed on its side (the valve slightly lower than the bottom) and the valve opened, the liquid rushes out and as it escapes some of it evaporates, absorbing heat from the residue. This residue becomes a solid with a temperature of −80°C. "Dry ice" is used in the preservation of foods and in the shipment of ice cream. The rapid freezing at a low temperature does not injure meats and vegetables as does ordinary freezing. Hence food frozen by "dry ice" keeps indefinitely with no loss of flavor. Many frozen vegetables and berries are furnished to hotels during the winter.

The *mechanical refrigerator* makes use of the heat absorbed as a liquid evaporates. The liquid must be one which boils at a temperature below the melting point of ice and which can be changed easily from the vapor to a liquid state. Some satisfactory liquids are sulfur dioxide (B.P. −10°C.), methyl chloride (B.P. −24°C.), and ammonia (B.P. −38°C.).

The liquid is placed in a partial vacuum in a system (Fig. 147) consisting of the expansion chamber *R* in the food box, a

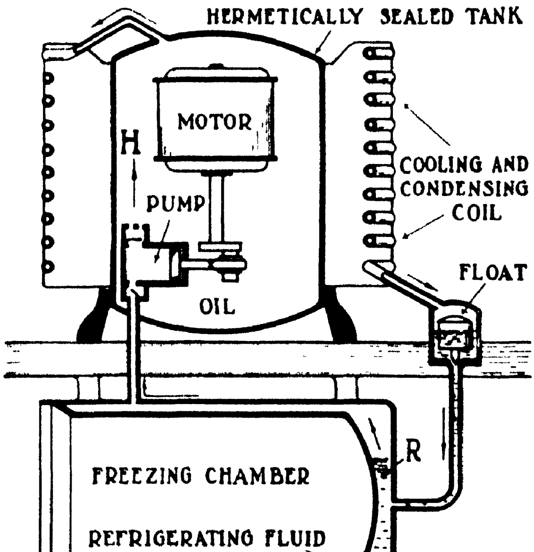


FIG. 147 —A simplified electrical refrigerator. (*Foley.*)

compression chamber *H* above the food box, and the connecting pipes. Heat coming from the food causes evaporation in *R*. The motor in the compartment *H* compresses this vapor and it is passed through the condensing coils where it becomes a liquid. The liquid returns to the expansion chamber through the float. Such a refrigerator is satisfactory as long as no gas escapes to the air, and as long as the motor functions properly. A good mechanism is rather expensive so that a cheap refrigerator is likely to be a liability. Perhaps it should be emphasized that the only essential

difference between an ice refrigerator and a mechanical one is that the latter provides a means for conserving the refrigerant so that it is used over again without loss.

Unlike the electric refrigerator, the *gas refrigerator* has no moving parts. Its action depends upon the fact that ammonia is much more soluble in cold water than in hot water. At 32°F., one quart of water will dissolve 1300 quarts of ammonia; at 68°F., about 700 quarts; and less at higher temperatures. A strong *solution* of ammonia is heated by a small gas flame. As the temperature of the solution rises, some of the ammonia evaporates and is condensed to *liquid ammonia* in the rectifier. The heat from the food chamber causes this liquid ammonia to evaporate. The gas is dissolved in cold water again so that the process is continuous. In the newest type the only requisite is a small gas flame, which can be produced by either a liquid or gaseous fuel.

FUELS

There are three types of fuel; solid, liquid, and gas. The value of a fuel depends principally upon the heating units it contains. The heat value is expressed in B.T.U. per pound, or in the case of gases, in B.T.U. per cubic foot. Solid and liquid fuels also contain sulfur and other impurities which sometimes make them undesirable. A good solid fuel should have a high fuel value, low ash content, and be free from volatile matter including sulfur. In the table the analyses of several typical fuels are given:

	Volatile Per Cent	*Carbon Per Cent*	*Ash Per Cent*	*Sulfur Per Cent*	*B.T.U. per Pound*
Peat (Florida)	56 83	24 30	15 68	49	8,930
Lignite (Dakota)	59 19	26 75	11 43	3 54	6,970
Bituminous (Coalport)	19 68	71 21	7 79	992	14,600
Anthracite (Lehigh)	5 00	86 00	9 00	50	13,570
Coke (Koppers)	70	91 86	7 50	69	13,000
Oak Wood	.		.	.	10,320
Gasoline			. .		20,000
Alcohol	. . . . .	. . .	. .	.	12,000

HEAT TRANSFER

Heat is a form of energy which moves from place to place. We receive heat from the sun; from the hot air furnace, and from stoves. Heat energy is transferred in three different ways, although any heating device may utilize more than one method.

CONVECTION. The type of heat transfer called convection is rather easy to understand. If one heats a kettle of water on the stove and places a little red dye in the bottom of the kettle, it will be noticed that very soon the entire volume of water will be colored The hot water at the bottom becomes less dense and rises to the top. In this way, a circulation is started that affects the whole mass of the water. In hot water heating systems, the water is heated in the boiler in the basement, rises through pipes to the radiators on the upper floors, loses heat, and returns to the basement as cool water.

Air also conveys heat by this method Our storms, as we have seen (p. 161) are due to heated air rising to the upper atmosphere and cool dense air rushing in to take its place. Ocean currents such as the Gulf Stream, and wind belts such as the Trade Winds (p. 159) are examples of convection currents.

In the hot air furnace (Fig. 148), dense, cold air passes through the jacket over the heated dome of the furnace, expands and rises through pipes to registers. From there it rises to the ceiling of the room. The cold air on the floors being heavier, sinks to the basement, starting a circulation. Although hot air heating is an excellent type, too often, improper installations make it very inefficient. Registers should never be placed under windows, since the cold air entering will blanket the rising air. Sometimes such registers will act as cold air ducts instead of hot air inlets. Every hot air installation should be constructed according to correct scientific principles. Although rising air is a good carrier of heat, when prevented from moving it acts as an excellent insulator. Wool and fur are warm because they have little spaces in which air is trapped. Every camper knows that a sleeping bag is better than many blankets. The air trapped in the bag acts as an insulator. If paper, asbestos, or felt is placed between the walls of

the house, the trapped air prevents the escape of heat. (It is incorrect to say entrance of cold unless we mean the entrance of a current of cold air.)

CONDUCTION. If one places a solid silver teaspoon in hot liquid, it will be noticed that in a very short time the handle will become hot. Likewise, the metal handles of hot cooking utensils are usually warm, although the handles are not over the flame. A boy who places his tongue on a piece of metal which is very cold

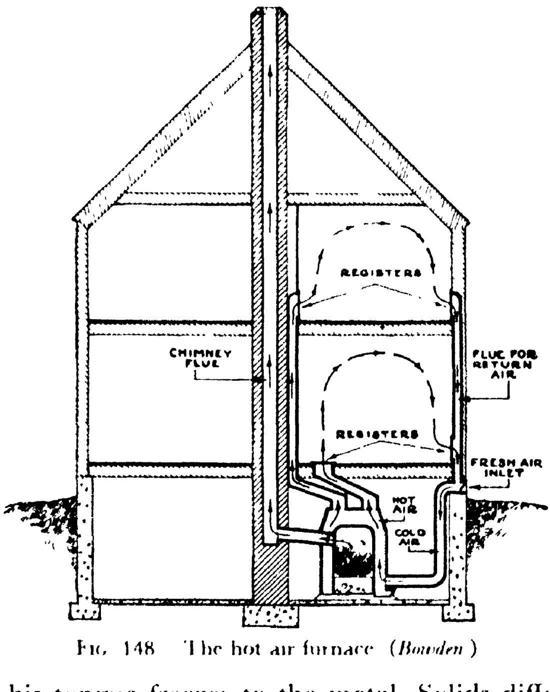


FIG. 148 The hot air furnace (*Bowden*)

finds that his tongue freezes to the metal. Solids differ in their conductivity for heat. Silver is the best conductor, while wood and wool are poor conductors. Aluminum, also a good conductor, makes excellent cooking utensils because it distributes the heat rapidly with less possibility of burning the food.

Heat is transmitted through solids (liquids and gases are poor conductors of heat) in some manner not well understood. If one end of a bar is heated, it is thought that the free electrons in the bar move faster and, because of their collisions with atoms,

cause the heat to move through the substance. If we place one end of a copper rod and one end of an iron rod in a flame, we shall discover that in a very short time the opposite end of the copper rod will be hot. The iron rod will become hot more slowly. Metals which are excellent conductors of heat are also excellent conductors of electricity.

An interesting demonstration can be performed by the use of several metal rods. If rods of aluminum, copper, brass, and iron are so arranged that one end of each can be heated with a common flame, and if a bit of paraffin is placed on each at the same distance from the flame, one can study the conductivity by noting the order in which the globules of paraffin are melted.

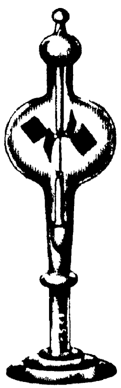


FIG. 149. The radiometer. (*Courtesy Central Scientific Company.*)

RADIATION. The third method of heat transfer, radiation, is the most universal but at the same time the most mysterious. All our lives we have received heat as a result of energy being transmitted through the 93,000,000 miles that separate us from the sun. But when it is remembered that the temperature of the interspace is probably nearly that of absolute zero, and that most of the space is a more perfect vacuum than any that can be produced on the earth, it will be seen that neither conduction nor convection can in any manner account for the heat transference. The energy travels with the speed of light and is possibly transmitted in the form of electromagnetic waves sent out into space by some disturbance of the atoms in the sun. This energy is transferred to objects on the earth. This theory is fully discussed in Chapter 13.

If the radiation falls on a highly polished piece of metal, like a tin roof, some of the waves are reflected just as light is reflected from a mirror. If, on the other hand, the radiation falls on black cloth, nearly all will be absorbed and the cloth will become hot. Because of the reflecting power, we wear white clothes in summer. The radiometer (Fig. 149), a familiar sight in opticians' windows, rotates because of the radiant energy it receives. The vanes receive unequal heating, the black side being heated faster than the polished surface. Consequently, the air molecules rebound from the black surface and this surface in turn moves away from the source of heat.

A greenhouse is a good example of the effect of the waves of energy. Sunlight, which is composed of waves of various lengths, strikes the glass. Some wave lengths penetrate and some are absorbed. The waves which pass through the glass strike the soil inside and are changed into heat (infra-red) waves. These long waves cannot escape through the glass and are trapped,

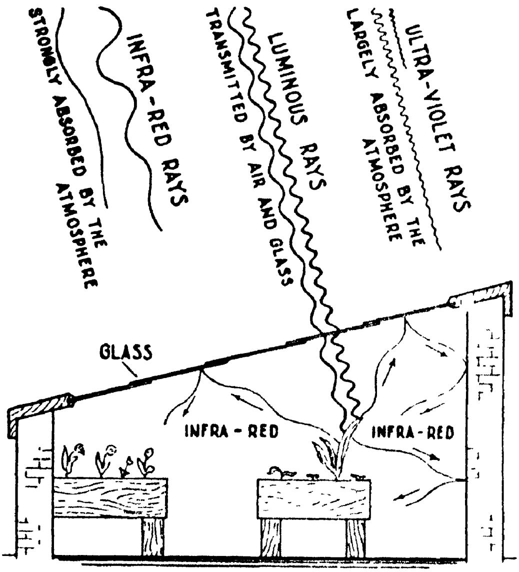


FIG. 150.—Illustrating the action of a greenhouse. The light waves are transmitted by the glass and upon striking the earth are changed into heat waves which cannot escape (*Foley.*)

thus warming the ground. Glass will transmit high temperature radiation (light), but will not transmit low temperature radiation (heat). The greenhouse is a heat trap. Many people are mystified by the fact that a greenhouse or a sun parlor is often warm on a sunny day in winter even though the temperature is low out of doors (Fig. 150).

HEAT ENERGY APPLIED TO MACHINES

Man has applied the principles of heat to the steam engine and to the gasoline motor. Many a boy has used a small jet of steam to drive a paddle wheel. Today, this principle has direct

application in the *steam turbine*, which is one of the most efficient of all engines. High pressure steam jets strike the turbine blades in such a way that nearly all the energy of the steam is utilized. Such turbines are used on many large ships.

The *steam engine* of the type used in locomotives was developed by several inventors, among them Newcomen and Watt. Watt's principal improvement to the steam engine was a device to make

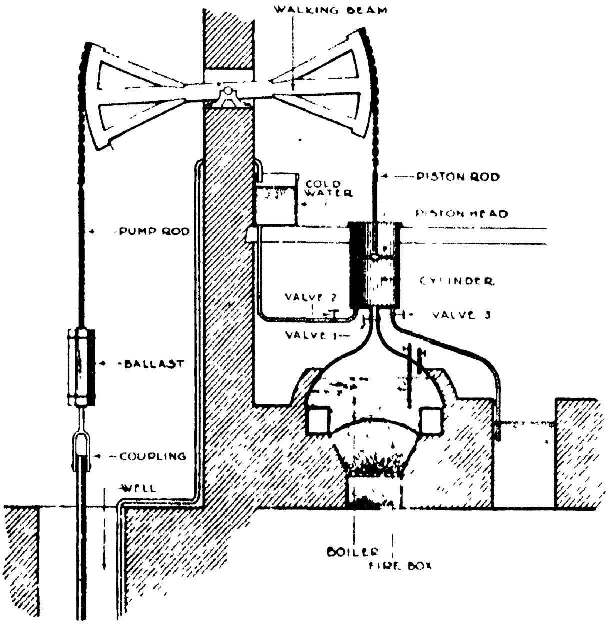


FIG. 151.—The Newcomen engine (*Bowden.*)

the operation automatic (Fig. 151). In the modern engine, the firebox produces steam under a pressure of several hundred pounds per square inch. This high pressure steam enters the cylinder, moving the piston as it expands. When the piston has reached the end of its stroke, the slide valve moves so that the steam enters at the other end of the cylinder, forcing the piston back to the original position. This operation is continuous as the piston motion drives the engine (Fig. 152). Some attempts have been made to replace steam by mercury vapor which makes a

more efficient engine. Thus far the mercury engine is in the experimental stage.

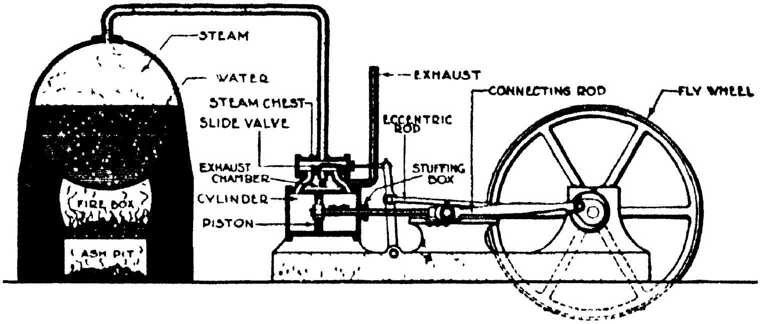


FIG. 152 Model of a modern steam engine (*Bowden*)

In contrast to the steam engine in which we have a fire-box and a cylinder, the *internal combustion engine* burns the fuel

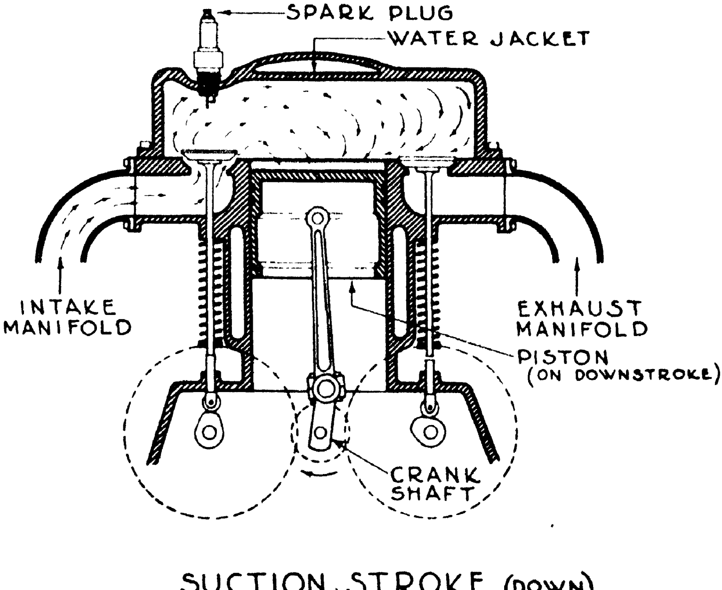


FIG 153.—(*Bowden.*)

inside the cylinder. In the gas engine, combustible gases mixed with air are pulled into the cylinder from the carburetor by the downward stroke of the piston (suction stroke) (Fig. 153).

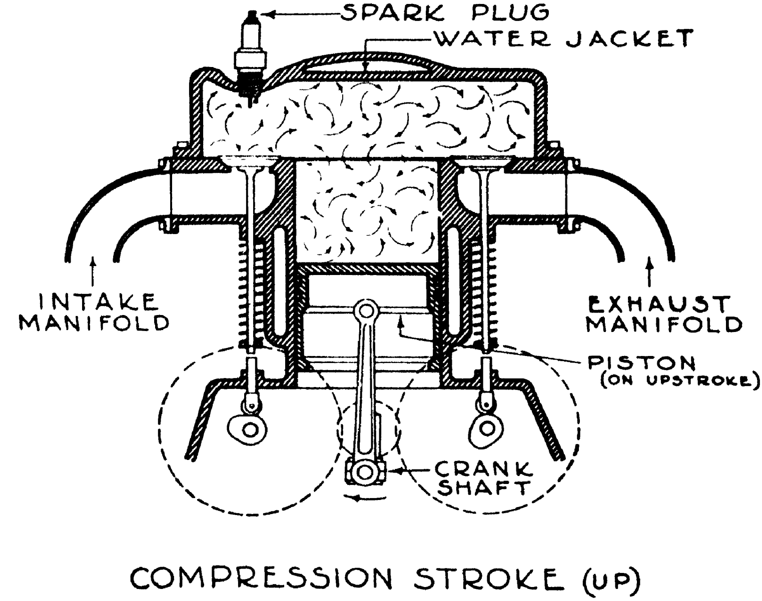


FIG. 154.—(*Bowden.*)

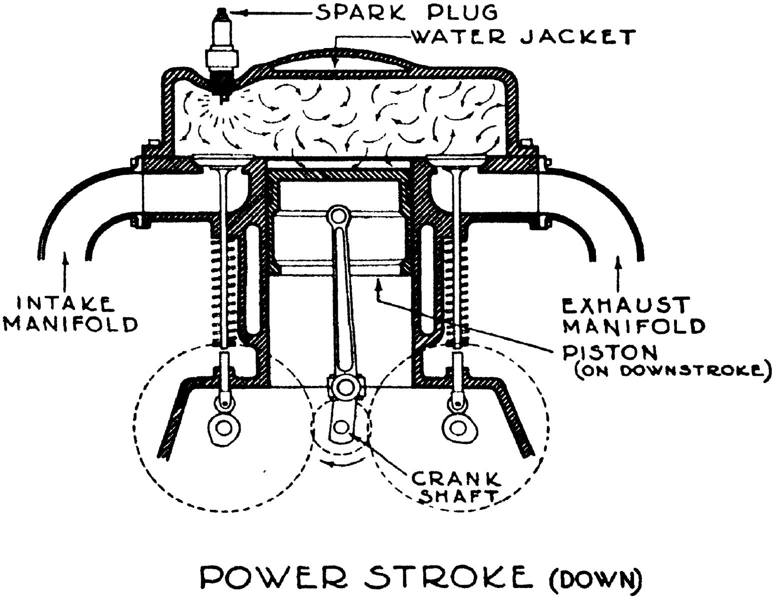
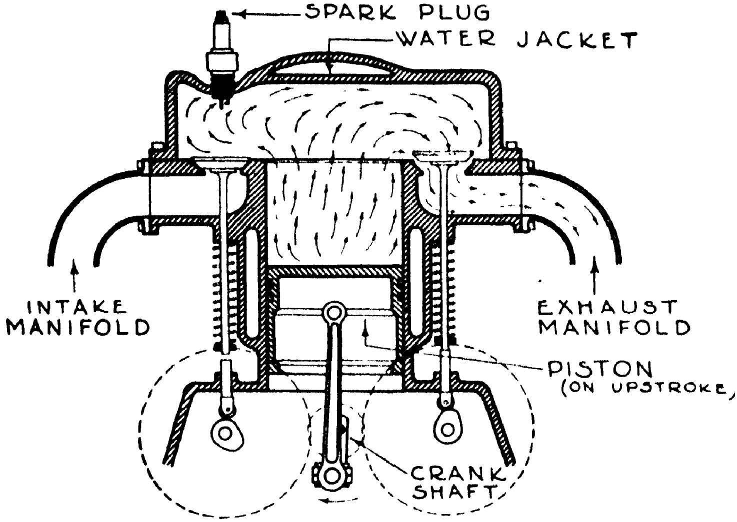


FIG. 155.—(*Bowden.*)

The rising cylinder in the compression stroke (Fig. 154) compresses the mixture of gases to a small volume. At this stage both valves are closed. The spark plug now fires the compressed gases, forcing the piston down in the power stroke (Fig. 155). The power stroke does work on the crankshaft of the engine. The rising piston now forces the burned gases out through the exhaust valve (exhaust stroke). (Fig. 156). The next cycle is another suction



EXHAUST STROKE (UP)

FIG. 156.—(*Bowden.*)

stroke. The four strokes constitute 4 cycle operation. In the automobile motor having several cylinders, the firing proceeds in such a way that each cylinder in turn acts on the crankshaft in such a time interval that smooth motion is produced. In recent years, the tendency of automobile designers has been to produce high compression motors. Unless a material is mixed with the gasoline to retard the combustion, the mixture may explode before the piston is ready to descend. This causes a "knock" which is harmful to the motor. One of the materials used as an "anti-knock" is lead-tetra-ethyl.

Just recently, another type of internal combustion motor has become important in commercial life. This motor, the *Diesel engine*, is now in use on steamships and in many large power plants. Some trucks are now powered with Diesel engines.

The Diesel engine is a compression type in which the compression ratio is about 16 to 1. This is much higher than the gasoline engine which we have described. The Diesel engine has no carburetor in which the air and gas are mixed. Instead, the fuel is blown into the cylinder through a small opening called the injector. Because the cylinder is already filled with very hot air under high pressure, the oil burns without a spark. It is estimated that the compressed air is at a temperature of about 1000°F. This temperature is hot enough to fire the oil without the use of any flame. The engine is very efficient.

It has been found possible to use almost any liquid fuel in the Diesel engine, but it operates best with a good quality fuel of the type of kerosene. Because of the high compression needed, it has not as yet been found feasible to build such engines for use in passenger automobiles. However, we may expect to see such engines on passenger cars in the near future.

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PROBLEMS

1. If the humidity is 100% is a fan helpful?
2. In hot, dry, countries porous bags are filled with water and placed in the air to cool. Why?
3. Marble always feels cool even in summer. Why?
4. Why is ice placed in the top of an ice box instead of at the bottom?
5. Why do patches of dirty snow melt more rapidly than clean ones?
6. Why do we discard dark clothing in summer?
7. Explain why gasoline feels cold when spilled on the hand.
8. Why is a greenhouse or sun parlor warm on a sunny day in winter?

9. If the temperature is 40°F. what is it C.?
10. If a thermometer reads 27°C. what will be the Fahrenheit reading?
11. Give a list of instruments which will measure temperatures from -100°C. to 3000°C.
12. Why was Galileo's thermometer unsatisfactory?
13. 30°C. equals how many degrees Absolute?
14. Normal body temperature is 98.6°F. What is the Centigrade reading?
15. How many calories will be given out by a steam heating system if the steam enters at 100°C. and leaves as water at 60°C.? Answer. 579 calories gram.
16. Why is a steam burn more serious than a boiling water one?
17. Why is a pressure cooker often used?
18. What is meant by absolute zero?
19. Why not use water for a thermometer material?
20. Describe the cycles of a four cycle gasoline engine.

TOPICS

Heating Systems
Biography of Rumford.
Clock Pendulums.
Thermostats.
Electric and Gas Refrigerators
Expansion Joints
Automatic Fire Sprinklers
Recording Thermometers
Thermocouples

VISUAL AIDS

HOW THE ICING UNIT WORKS General Electric Company.
REFRIGERATION—Eastman Classroom Film.

EXPERIMENTS

1. Make a study of thermostats. Investigate the construction of one in the schoolroom, in the incubator, in the electric refrigerator.

2. Study conduction of heat. Place the ends of 4 rods, copper, iron, brass and aluminum in a flame and record the time intervals until the other ends of the rods become hot.

3. Study a simple fire sprinkler. Cork a glass flask, which is partly filled with water, with a one hole rubber stopper. Plug one end of a short glass tube with Wood's metal and insert the tube in the stopper. Invert the flask and gently warm the metal in the tube with a candle flame. Water will flow out and extinguish the candle.

4. Place a beaker of water over a flame and by means of a medicine dropper place a little red dye at the bottom of the beaker. As the water becomes warmer the dye will circulate through the entire beaker. This is convection.

5. Make a table of some of the liquids used as refrigerants. Secure information concerning odor, boiling point, chemical properties, and physiological

properties of sulfur dioxide, methyl chloride, methyl formate, "carrene," carbon dioxide, and ammonia. Decide which is the best liquid for domestic use.

6. Visit a power plant for the study of steam engines, gas engines, and Diesel engines. Make a sketch of a 4 cycle engine, including one drawing for each cycle. If possible secure an old 4 cylinder, or still better, a one cylinder gasoline engine, and examine the valve construction. This makes a very valuable experiment for general science classes.

17

ENERGY MANIFESTED AS LIGHT

"The Great World of Light, that lies
Behind all human destinies."
Longfellow

ONE OF the great mysteries of science is the phenomenon of light. We assume that we see objects about us, and that we distinguish the colors of objects by means of the light which enters the eyes but, as yet, a complete explanation of the phenomena of seeing and of light transmission has not been given. In the discussion of the atom, it was stated that there are two theories which attempt to explain the method by which light is transmitted from one object to another. One theory assumes waves in space, and the other theory treats of quanta (corpuscles). We shall assume in the present chapter that light transmission is a wave motion. It seems probable that the emission of light from a hot body such as an electric lamp is due to the motion of electrons in the atoms of the filament.

Ordinary white light seems to result from the composite of a great many different electronic motions; it is possibly produced by the complicated motion of one electron in the atom. Light of a single wave length (*monochromatic*) is probably due to one simple vibration of the electron. We have seen that the eye responds to a small band of electromagnetic waves extending from .00008 cm. (red) to .00004 cm. (violet). This is known as the visible spectrum.

Light travels in straight lines. Anyone who sights a gun is making use of the principle. Objects cast sharp shadows. The moon is so small compared to the sun that, if the light curved around the edge of the moon, an eclipse of the sun would be impossible. Although light does bend slightly when passing through a narrow slit, as we may notice when viewing a bright light through nearly closed fingers (see p. 192), for our present purpose we shall assume that light travels in straight lines.

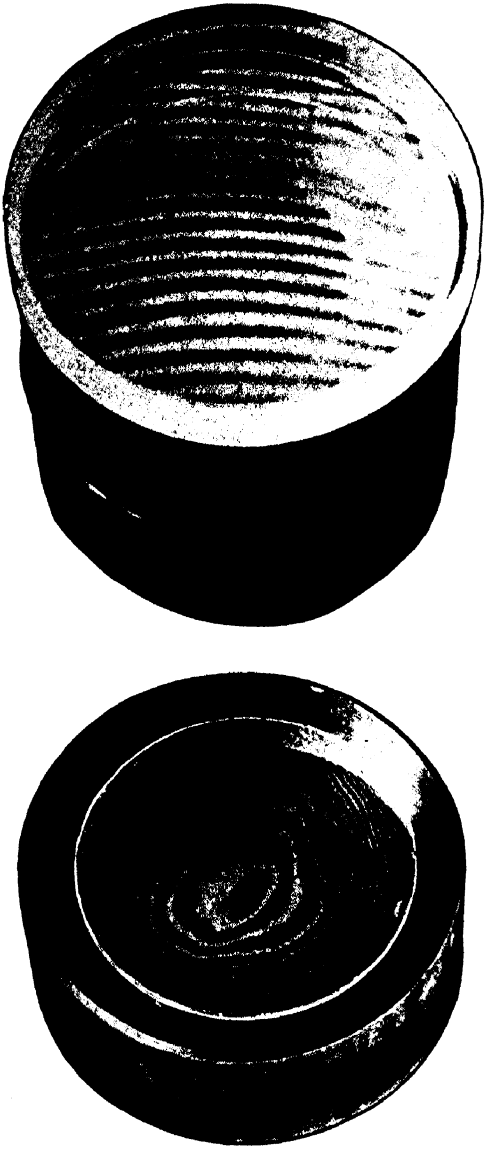


FIG. 157.—The interference of light waves between two glass plates is used to test the surface. An irregular surface will produce fringes as shown in the lower figure. If the surfaces are quite smooth the fringes will appear as in the upper figure. (*Courtesy Bausch and Lomb Optical Co.*)

In Chapter 13, it was stated that Newton believed light to be composed of corpuscles traveling in straight lines. Young showed that interference, a wave phenomenon, could be produced by the action of light from two sources.

One commercial use of interference is for testing the irregularities of glass surfaces. In Fig. 157 the irregular fringes indicate that the lens is not satisfactory. In the upper figure, the symmetrical bands show that the surface is correctly ground.

REFLECTION

Perhaps our most common experience with light is reflection. We look into a mirror; we observe the blue of the sky; we notice

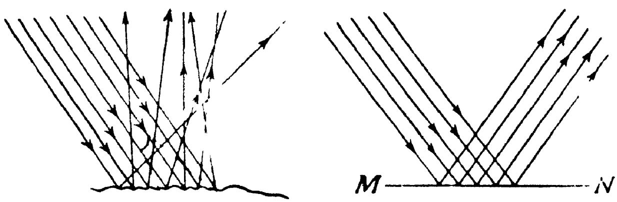


FIG. 158 - Diffuse and direct reflection (*Bowden*.)

that the clouds are white; we are aware that some types of paper give a glare and that some materials are dull. We decorate the walls of a room with light paint so that the light may be reflected instead of absorbed.

A mirror reflects a beam of light in such a manner that the reflected light leaves the surface at the same angle with the perpendicular that the incident light made with the perpendicular. In Fig. 158 the arrows pointing downward indicate the light striking the surface *MN*, while the arrows pointing upward show the direction of the reflected light. This type of reflection does not enable us to see the surface. All of us have at some time walked toward a large plate glass mirror, believing it to be an opening.

However, in most cases, the reflected light is scattered by rough surfaces such as painted walls or rough wood. In Fig. 158, we notice that the arrows indicating the reflected beams point in

different directions. We see articles in the room and out-of-doors because light is scattered by them. The blue of the sky is sunlight scattered by dust and air; the colors of the clouds are due to scattered sunlight. We may get snow blindness in winter and we may be sunburned in summer because of the scattered ultraviolet in the sunlight. Lighting engineers are endeavouring to eliminate direct lighting because of the glare which is harmful to the eyes, and to substitute indirect illumination produced by light scattered by light-colored walls.

ILLUMINATION

The study of illuminations has become very important in recent years. Until modern times, mankind made very little use of any illumination other than the sun. Most of his activities were confined to the hours of daylight. With the advent of modern methods of living, night illumination became necessary. Most of the comfort of modern lighting is due to the development of the electric light. Only four decades ago most of our light was produced by oil lamps. The Edison lamp, which consisted of a carbon filament in an evacuated glass bulb, was the first great improvement. However, the light was of poor quality (too large a proportion of red rays) and the lamp was expensive to operate. The next step was the use of tungsten wire instead of the carbon filament. This lamp gave a whiter light. In addition, the modern tungsten bulb requires less than $1/4$ as much electrical energy to produce the same amount of light as was produced by the carbon bulb. It was discovered that when tungsten is heated in a vacuum, the atoms of the wire slowly evaporate and settle on the walls of the bulb. This evaporation weakens the filament, and the evaporated tungsten blackens the bulb. To remedy this difficulty the bulb is filled with a mixture of argon and nitrogen. The atoms of the gas retard the evaporation, resulting in a longer life of the bulb, thus making possible better light because of the higher temperature at which it is burned. The modern bulb is frosted by spraying the inside of the glass with hydrofluoric acid (HF).

There is a great waste of energy in the production of light. Only about 5% of the electrical energy is transformed into light, the remainder being transformed into heat. The efficiency of a lamp is rated in candle-power per watt. This gives a measure of the candle-power of light emitted, per watt of electrical power.

LIGHT EFFICIENCIES (Approximate)

Lamp	*Candle-power per Watt*
Carbon filament lamp	.3
Tungsten filament lamp	8
Tungsten (gas filled)	14
Mercury arc in quartz	4.0
Carbon arc	20
Sodium vapor lamp	50
Green fluorescent mercury	60

If we wish to observe an object closely we place it very near a light. By this means we increase the illumination on the material. *Illumination* is measured by a unit called the *foot-candle.* If a candle of a certain specified size is held one foot from a book, the page is illuminated by one foot-candle. If a 36 candle-power lamp is placed three feet from the book, the illumination is 4 foot-candles. From this follows the relation

$$\text{Illumination} = \frac{\text{candle power}}{\text{distance squared.}}$$

$$I = \frac{\text{c.p.}}{D^2}$$

The eye is very adaptable and can adjust itself to a great range of illumination. However, experience has shown that most rooms are not satisfactorily illuminated. Classrooms should have about 20 foot-candles, which is equivalent to a 500 candle-power lamp at a distance of 5 feet. Since the best light is that reflected by the walls, an indirect light would need to be somewhat greater than this value. Modern engineers envision the room of the future without windows, and with indirect lighting, which will produce

a uniform soft light casting no shadows. In Figs. 159 and 160 modern illumination is contrasted with older forms of lighting. Many modern libraries already have indirect lighting. For

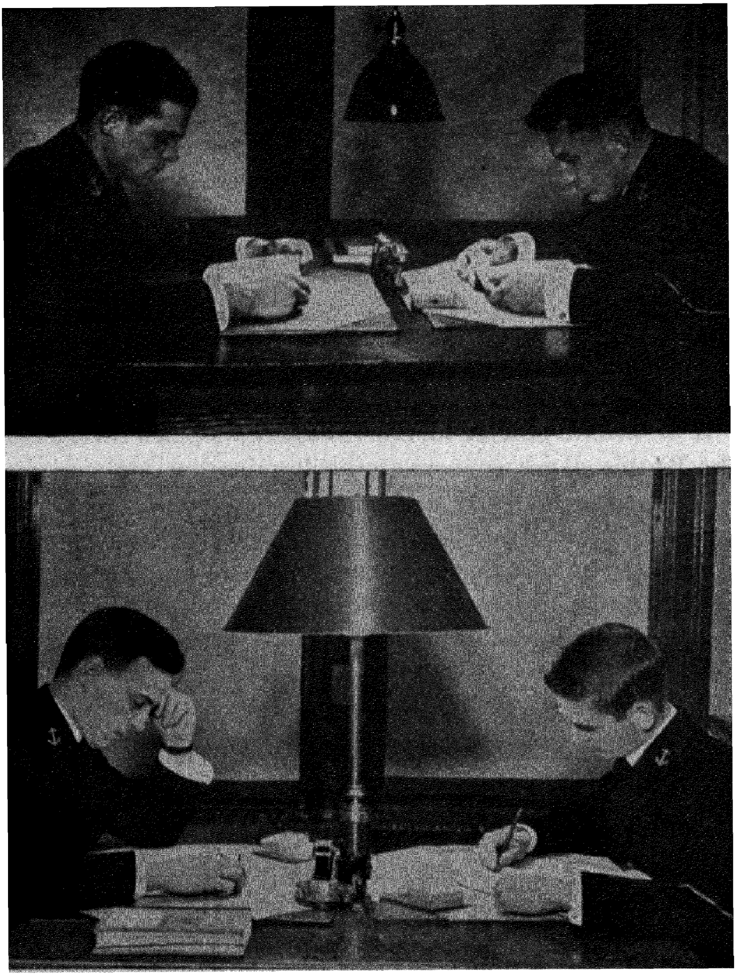


FIG. 159.—Illumination old and new. (*Courtesy General Electric Co.*)

best vision the eye requires sufficient light, absence of glare, steady light, and illumination of the proper color (sunlight or its equivalent).

COLOR

Man has always admired color. He enjoys the color of the rose, of the green foliage of the trees, and of brilliant dyes. Most colors

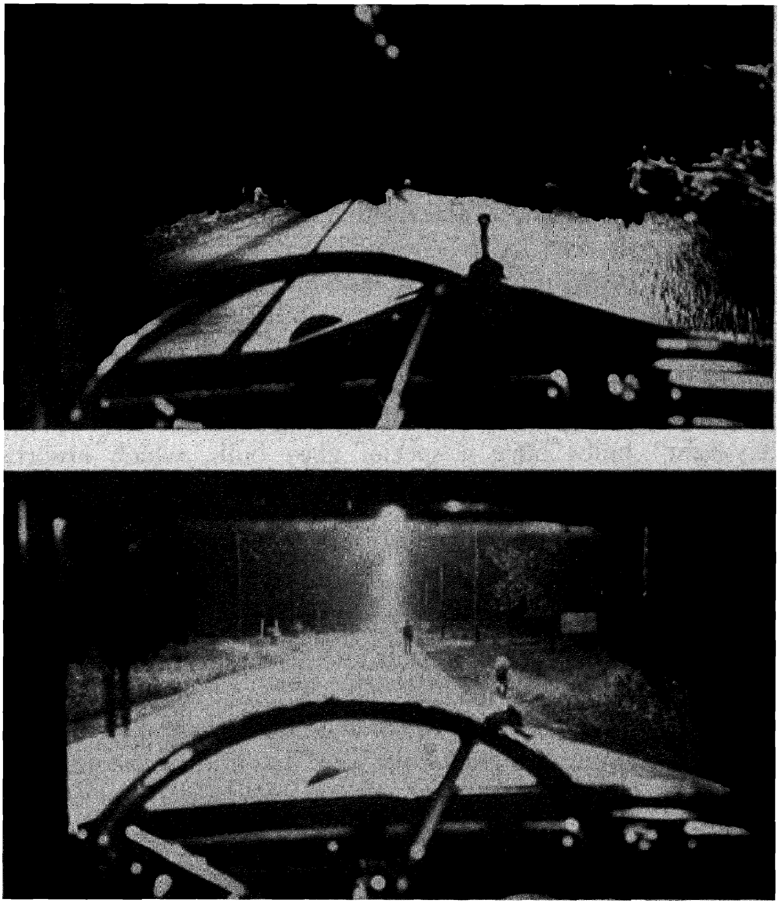


FIG. 160.—The new sodium highway light contrasted with old methods for road lighting. (*Courtesy General Electric Co.*)

are due to reflected sunlight. As the sunlight falls on a red rose, all the parts of the spectrum are absorbed by the flower except the red, which is reflected to the eye. We do not know just why the rose reflects red, but we can test the statement just made by view-

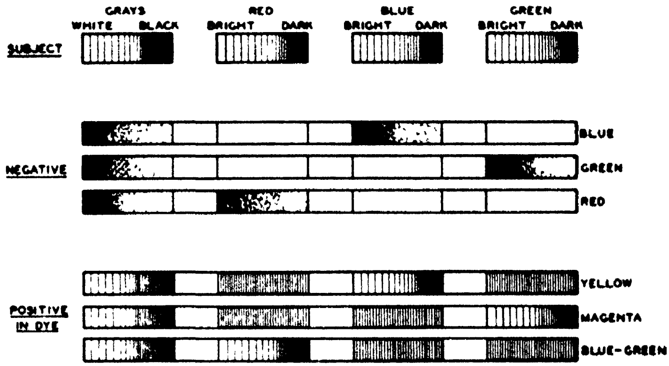
ing the rose under mercury light. Since there are no red rays in the mercury spectrum, the rose will appear black.

Perhaps the best theory of color is that of resonance If white light strikes the rose, most of the light becomes heat. The red part of the spectrum excites in the molecules of the rose, electronic motions which are in resonance with the frequency of the red rays. As a result red is emitted from the rose. Chlorophyll, the coloring matter in green plants, seems to absorb the red and radiate the green part of the spectrum. In some way this absorbed energy causes plant growth by utilizing carbon dioxide from the atmosphere.

If we place a piece of red glass before a lamp emitting white light, the glass absorbs all the spectrum except the red, which it transmits to the eye. By these two processes, reflected color and transmitted color, most of our colors are produced. We are conscious of color deficiencies when matching goods by artificial light. The electric light in clear or frosted glass is not the white light of the sun, so that articles, which are alike in color under artificial light, appear different in sunlight. The lamps called "day-light" bulbs have a special glass bulb, which absorbs certain portions of the spectrum, so that the resultant light is more nearly the color of sunlight. One reason why we do not use the neon lamp for reading is that the color is orange-red, which is not a comfortable light for general use. Just recently, a lamp containing mercury has been developed, whose light resembles sunlight rather closely. Perhaps in the near future we may have artificial sunlight.

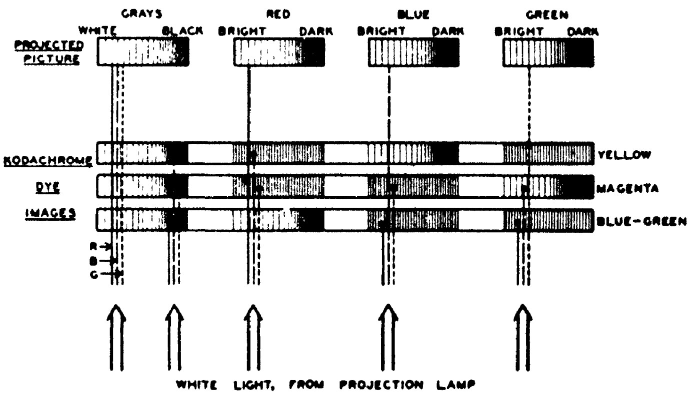
Just why the eye perceives color is still a matter of dispute. The ideas of Young and Helmholtz were that the retina contained special fibers which responded to the three sensations of red, green, and violet, transmitting these impulses to the brain as color. If all three sets of fibers are stimulated, the sensation is white light. By mixing two or more of these types of fibers, we get the sensation of such colors as orange, blue, and yellow. A fact which gave support to the theory was the eye deficiency called color-blindness. About 5% of our population are color-blind, mostly red-blind, which means that such persons do not perceive red as a color. The theory of Helmholtz held that the cause of color-blindness was the absence from the retina of red-

sensitive fibers. Unfortunately, there is no evidence of the presence of such fibers. There are other theories but, as they are not well established we shall not discuss them.



PRODUCTION OF COLORED IMAGES ON KODACHROME FILM

FIG. 161. (*Courtesy Eastman Kodak Co.*)



PRODUCTION OF COLORS BY KODACHROME FILM

FIG. 162.—(*Courtesy Eastman Kodak Co.*)

COLOR PHOTOGRAPHY

Until recently the photography of objects in color was expensive and complicated. The Eastman Kodak company have now developed "Kodachrome." In this film there are three gelatin

emulsions. In the raw film (Fig. 161), the blue sensitive emulsion is colored yellow, so that blue light is absorbed, and only the red and green get through. Only red gets through the green sensitive emulsion, the green being absorbed in this layer. The red rays act on the lowest layer. In processing the film, the images are reversed and dyed, the upper laver yellow, the center magneta, and the lowest layer blue-green. When white light passes through the film the pictures emerge colored. The colored sections are indicated on the schematic diagram (Fig. 162).

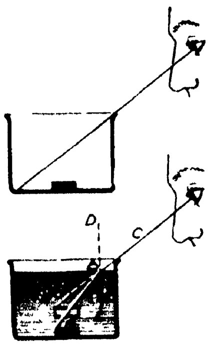


FIG. 163 —An experiment illustrating refraction. The upper cup is empty. The lower is filled with water. (*Bowden.*)

REFRACTION

A boy learns while fishing that an object under water is really deeper than it appears to be. If it seems to be three feet underneath, it is really much deeper. Likewise, a spoon placed in a tumbler of water, when viewed from the side appears broken at the surface (Fig. 163). Both of these experiments indicate that light travels more slowly in glass and water than it does in air. This variation in speed causes *refraction.* Refraction of light in the unsteady atmosphere causes twinkling of stars. Light refracted by water drops causes the rainbow.

	Miles per Second
Speed * of sodium light in water	147,000
Speed * of sodium light in crown glass	122,000
Speed * of sodium light in diamond	77,000

* (Since the speeds of the various wave lengths are different in different substances, the type of light must always be mentioned)

All types of light travel at the speed of 186,000 miles per second in free space. In Chapter 3 the method was described by which Michelson measured this enormous speed.

The index of refraction of a substance is the ratio of the speed of light in air to the speed in a substance. For example, the index of refraction of a diamond is 186,000/77,000 = 2.4.

LENSES

The most important product of the principle of refraction s the lens. It is difficult for us in these modern times to visualize in age without lenses, the "Eyes of Science." We wear them as pectacles; we use them in the microscope to study bacteria; by he lenses of telescopes, we study stars and planets. It is probable hat the first lenses were made in China. Marco Polo found

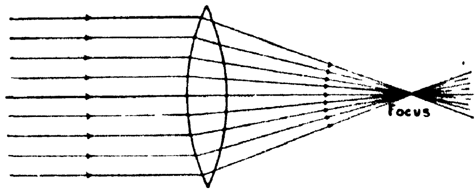


FIG 164 —The convex lens The focal length is the distance from the center of the lens to the point marked, focus

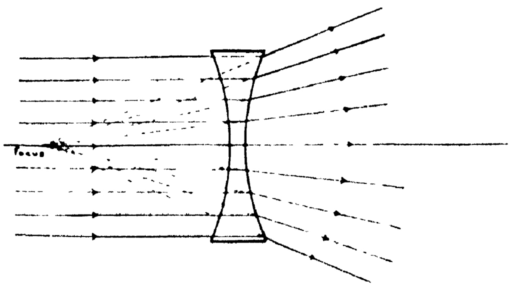


FIG 165 —The concave lens Note that the emergent light is diverging. This lens does not form a real image.

pectacles worn when he visited the Orient. In Europe, however, enses were practically unknown until Galileo, by grinding lenses, constructed one of the first telescopes. The microscope was first ised about 1630, but spectacles were not used until rather recent imes. Benjamin Franklin made some crude bifocals during the eighteenth century.

Lenses can be grouped under two types: those which spread out the light (*diverging*), and the *converging* type which focus light rays. If we hold a reading glass or the lens from a flash light in the sunlight, a small real image of the sun will be formed on a white

surface placed at the proper distance. In this case, the *distance from the lens to the image on the surface is called the focal length of the lens* (Fig. 164). The reading glass being thicker at the center than at the edge, is a convex or converging lens.

On the other hand, if one removes the eyepiece lens from an opera glass, and attempts to form an image, none can be found. Such a lens is a concave or diverging type which produces a virtual image. This lens is thicker at the edge than at the center (Fig. 165). Oculists classify lenses by the term *diopter*. *A diopter* (power of a lens) *is the reciprocal* of *the focal length in meters*. (A lens of 50 cm. focal length has a power of two diopters.) A convex lens is a *positive* lens; the concave lens is a *negative* lens. The modern lens system is usually a very complex combination of lenses designed to eliminate distortions of various kinds. (For a description of such lens systems the reader may consult the references.)

MICROSCOPES AND TELESCOPES

Both of these instruments consist essentially of two convex lenses, the objective and the eyepiece. In the refracting telescope (see p. 15) the objective is a lens of long focal length, and the eyepiece is one of short focal length. The *magnification of a telescope may be expressed as the ratio of the focal length of the objective to that of the eyepiece.*

The *simple microscope* (magnifying glass) is a lens of short focus. The object AM is placed inside the focus of the lens BN, and the image formed, I, is a virtual one (Fig. 166). The magnifying power is expressed as $\frac{\text{Reading distance}}{\text{Focal length}} + 1$. Since the reading distance for the normal eye is 10 inches, a 5 inch focal length lens would make the object appear three times as large. In the *compound microscope*, another convex lens is used as the objective lens (the lens nearest the object), and the simple magnifier forms the eyepiece. One can determine the magnification by multiplying the magnifying power of the objective by the magnifying power of the eyepiece. An objective with a focal length of 4 millimeters gives the highest practicable magnifying power in air, about 40. If the objective is immersed in cedar oil, we may use an objective

with a focal length of 1.8 millimeters. Such an objective gives a magnification of 100. When this objective is combined with an eyepiece of a magnifying power of 12.5, we can secure a magnify-

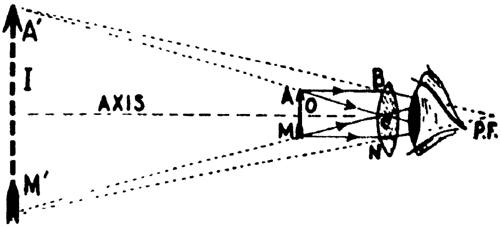


FIG. 166.—The simple magnifier. (*Foley.*)

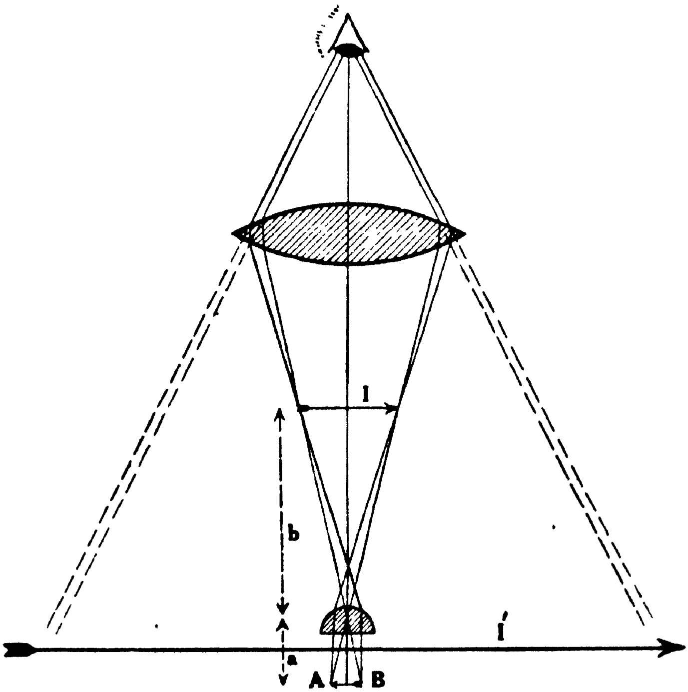


FIG. 167.—The compound microscope. (*Weld and Palmer.*)

ing power of 1250. This means that an object 1/1250 inches in diameter, appears to be one inch in diameter. The instrument is said to magnify 1250 diameters. In Fig. 167 the magnification of the *objective* is *b*/*a*.

A compound microscope is a very exact instrument and should have good care. Any beginner should consult some manual on the use and care of the microscope, before attempting to use the instrument. As has been stated (see p. 179), the feature which determines the use of the microscope is the resolving power. By using ultra-violet light, and replacing the eye by a photographic plate, it is possible to secure information concerning very small objects invisible under ordinary light. Such a photograph is called a *photomicrograph* (see p. 117).

THE CAMERA

A camera consists essentially of a light proof box with a convex lens at one end and a photographic plate or film at the other.

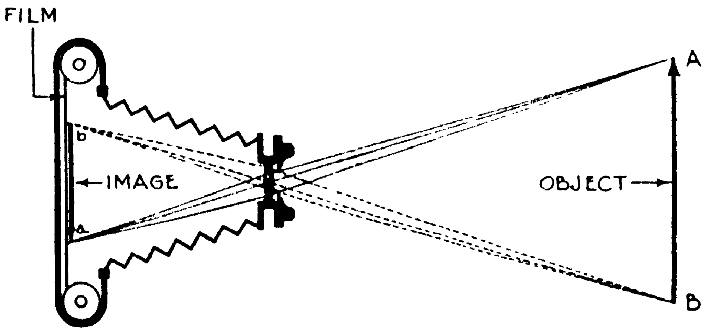


FIG. 168.—The camera. (*Bowden*)

There is also a shutter and a diaphragm to regulate the amount of light which enters the box. The small box camera ("Brownie") has a fixed lens of short focus which requires no adjustment. Although part of the photograph is not in sharp focus, fairly satisfactory pictures can be taken.

Usually the lens is mounted on a bellows, so that the distance from the lens to the film can be adjusted to secure the sharpest image (Fig. 168). The lens-film distance is short for distant objects and long for near objects. As the pattern of light falls on the film, a chemical change takes place in the silver bromide emulsion.

A photographic plate is made by coating glass with hot gelatin in which potassium bromide is dissolved. Silver nitrate is added in

the dark; the resulting reaction leaves crystals of silver bromide in the gelatin. This chemical compound is photo-sensitive; its chemical composition can be changed by the action of light (Fig. 169).

FIG. 169.—The stages of making a photograph. (*Courtesy Eastman Kodak Co.*)

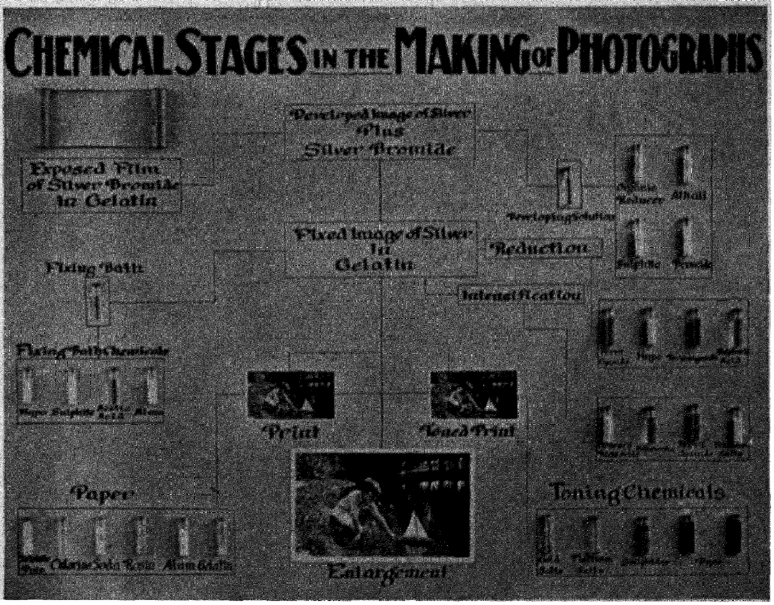


FIG. 170.—(*Courtesy Eastman Kodak Co.*)

Although the exact chemical reaction is not well understood, most investigators believe that light changes silver bromide ($AgBr$) to di-silver bromide (Ag_2Br). The dark parts of the object being photographed, do not affect the silver bromide to the same

extent as the light parts. The film is now placed in a solution (such as pyrogallic acid, hydroquinon, amidol, or metol) which develops by changing the exposed silver bromide to silver. The unchanged silver bromide is removed by immersing (fixing) the film in sodium thiosulfate (hypo). The result is a negative, so called because the light parts of the object photographed are the dark parts of the film. In making a print the film is placed between a light and a paper which is photosensitive. This paper when developed and fixed is the desired photograph (positive). (Fig. 170.)

By means of a diaphragm (iris) the amount of light entering the camera can be regulated. The diameter of the opening is expressed as a fraction of the focal length of the lens. For example, $F/10$ means that the diameter of the aperture is $1/10$ of the focal length of the lens. A small aperture admits less light but produces sharp images. For sharp pictures it is desirable to use the smallest opening justified by the illumination. In general, $F/11$, or $F/16$ are the best. $F/4.5$ and $F/6.3$ must be used with caution.

The most essential feature of a camera is a good lens. Camera lenses are sometimes very complex, being composed of several lenses in a train. Some of the types frequently used are rapid rectilinear, anastigmat, and portrait. A very good lens is the anastigmat which is found on better cameras. A rapid rectilinear lens gives an image which has the same shape as the object. An anastigmat gives an image free from astigmatism.

During the past few years there has been a marked improvement in the sensitiveness of emulsions. By means of special dyes, the film can be so treated that the silver bromide will be affected by both the visible and the infra-red part of the spectrum. The oldest type of film is the orthochromatic, which contains the dye *eosin*. The film is sensitive from the ultra-violet to the yellow portion of the spectrum. Since the film is not affected by the red portion of the spectrum, it can be developed in a room illuminated by red light. A newer film, the panchromatic, is sensitive to all parts of the visible spectrum and is best developed in the dark. Recently a film that responds to the infra-red spectrum has been developed. This is a very useful film for the experimenter in the heat region. A photograph can be taken of an hot object in

complete darkness. Infra-red films are very useful in a study of the constitution of planets (Fig. 171).

THE EYE

The eye (Fig. 172) is a camera in which there is a convex lens and a sensitive screen (retina). The lens is a double convex

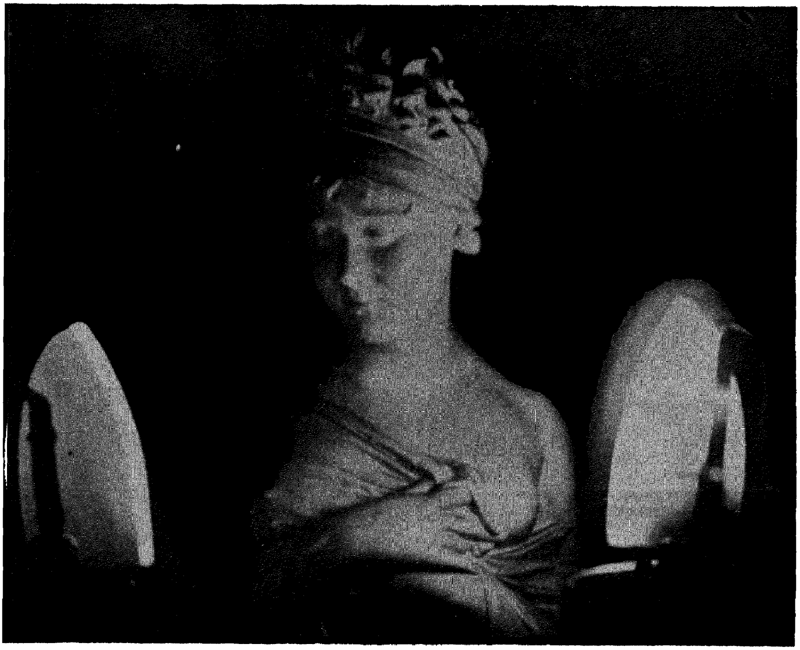


Fig. 171.—A photograph of a plaster bust made without visible light by the use of heated flatirons. This photograph was made by the Eastman Infra-Red film with an exposure time of fifteen minutes. (*Courtesy Eastman Kodak Co.*)

type made up of several layers. To adjust the eye for distance vision, the controlling muscles decrease the curvatures of the lens surfaces, thus forming a long focus lens; for near vision, the lens becomes one of short focus. The lens forms a real, inverted image on the retina. The principle of the transmission of the light impulses to the brain is being studied intensively, but as yet the phenomenon of seeing is not well understood. There is no good explanation of vision.

CORRECTION OF THE ERRORS OF THE EYE LENS. Optically, the eye is subject to several errors which can be corrected by spectacles. In the case of myopia (near sight) the patient does not have

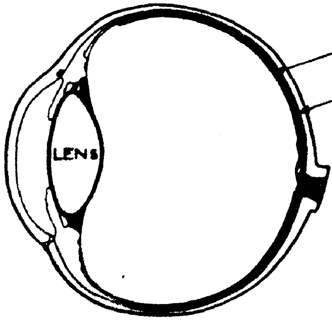


FIG. 172.—The schematic eye showing lens, retina and choroid coat only.

the ability to change the focal length of the eye lens sufficiently to see distant objects distinctly. The eye lens has too short a focal length. The oculist prescribes a concave (negative) lens, which

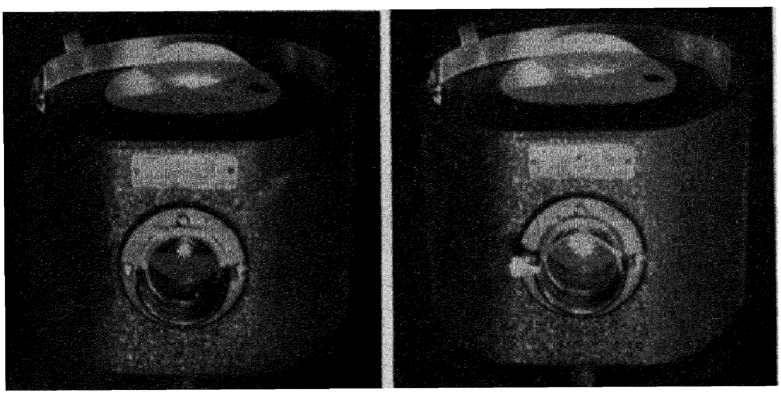


FIG. 173. Model of the eye to show correction for nearsight. The left "eye" has the retina too far from the lens and the image is indistinct. The right "eye" has a concave lens in front of the eye lens. Note that the image is now distinct and in focus.

has the effect of producing a longer focal length so that the wearer has normal distance vision (Fig. 173). It is important to understand that the difficulty is not actually removed, but is remedied.

Myopia is quite common in young persons. In the opposite condition, *Hyperopia* (far sight), the focal length of the lens is too great. To remedy this condition a convex lens is prescribed.

Probably the most common error is *astigmatism*. This difficulty is due to a lack of symmetry of the eye lens. An astigmatic person finds that when some of the figures on a clock face are distinct, others seem blurred. The constant effort to overcome this condition produces eye strain and headache. The teacher should be on the watch for symptoms of this kind in children and should advise early correction. To remedy this condition the oculist prescribes a lens cut from a glass cylinder.

The fourth condition, *presbyopia* (loss of accomodation), affects the person in middle-age. The eye lens has lost the power of adjustment for near vision, so that glasses must be worn for reading. Most middle-aged people wear bifocal lenses.

The newest type of spectacle lens is one which is placed under the eyelid directly on the eyeball. A thin film of salt solution on the ball prevents irritation. These lenses are invisible and are said to be perfectly comfortable for the wearer. Unfortunately, their cost is rather high at present.

TELEVISION

For centuries man has desired to enlarge his range of vision in order to be able to see events hundreds of miles distant. Various devices have been constructed in the past, but none of them gave satisfactory results. Within the last ten years, the problem has been successfully solved by means of the photoelectric cell. (See p. 193.) In general, the problem of television is that of converting light energy into electrical energy, transmitting the energy by radio waves, and finally converting the electrical energy back into light energy at the receiving station. The most successful methods seem to be the ones developed in 1933–1934 by Zworykin at the Radio Corporation of America, and by Farnsworth in Philadelphia. Baird in England and an investigator in Germany have also produced successful television systems. We shall describe the apparatus of Zworykin. In order to do this it is necessary to describe the retina of the human eye.

The retina of the eye is a mosaic pattern of nerve elements, consisting of three layers of neurons. The layer of nerve cells nearest the eye lens, is composed of the optic nerve cells; the bipolar cells form a second layer; the layer against the choroid coat at the back of the eyeball is made up of rod and cone cells. This means that in the third layer the dendrites of the neurons are rods and cones. The rods and cones are very numerous, the number of cones in the yellow spot of the retina alone being about one million. Interlaced with the rods is a mosaic of pigment cells, the visual purple. When the image is focused on the retina by the eye lens, the light waves pass through the retina to the rod and

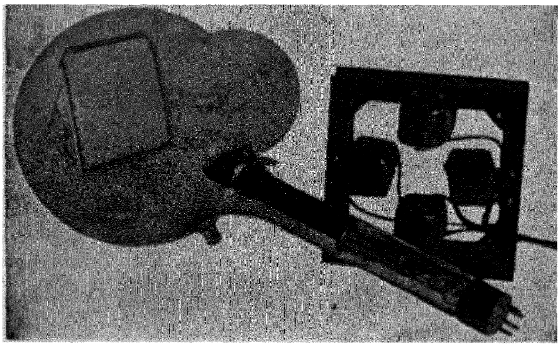


FIG. 174.—The iconoscope. (*Courtesy Radio Corporation of America.*)

cone layer. These rods and cones are photosensitive, and when stimulated by light, produce impulses which pass through the optic nerve cells to the brain. It seems that the *retina acts like a self-restoring photographic film*. For our purpose, we shall describe the *retina as a mosaic of light-sensitive rods and cones.*

Zworykin, imitating the action of the human eye, designed a photoelectric cell (Fig. 174), with a mosaic consisting of many thousands of tiny silver globules, each made photosensitive by a coating of cesium (Fig. 175). These globules were deposited on an insulating enamel covering the metal plate (signal plate). The silver mosaic and the signal plate constitute an electrical condenser. The image is focused in the usual manner on the sensitive surface by a camera lens, thereby causing an emission of electrons. The number of electrons emitted by each element depends upon

the intensity of the illumination. When the electrons leave the globules, the globules are left positively charged. A beam of electrons shot out by the electron gun shown in the figure moves over the surface and neutralizes the positive charges. This process causes a current of electricity through R. This feeble current is amplified by radio tubes and is broadcast in the usual manner. This device called an *iconoscope* (see an image), replaces the film of a camera By means of this camera, objects can be televised out of doors. It is expected that within a few years television equipment will be found in many homes. There are many difficulties to

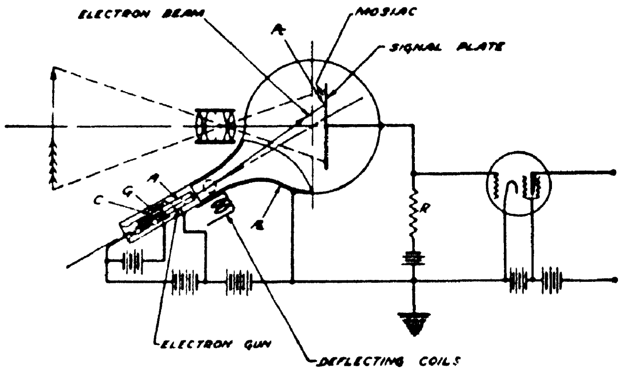


FIG 175 — Electrical circuit of the iconoscope (*Courtesy Radio Corporation of America.*)

be overcome. Static is very disturbing in television, causing a blurred image.

Previous to the invention of the iconoscope, all television equipment contained a rapidly moving scanning disc. The new device, having no massive moving parts, is a distinct advance. One interesting use for the iconoscope may be the study of objects too small for the microscope. The equipment responds to the ultra-violet and can act as a microscope for that region.

SOUND MOTION PICTURES

Modern motion pictures combine two applications of light principles. The film contains a series of photographs taken of moving objects. As these are jerked between a lens and a light source at the rate of 16 per second, the eye, because of the persist-

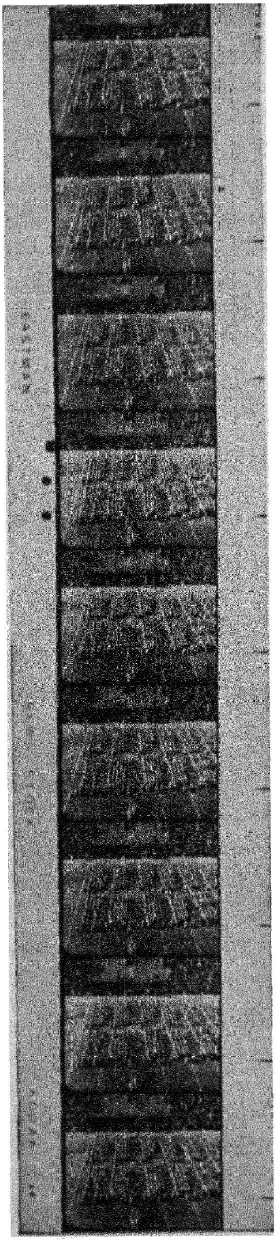


Fig. 176.—Sound film.

ence of vision, registers these images as continuous motion of the photographed objects. (Persistence of vision means that the retina retains an impression of an object for $\frac{1}{16}$ of a second.)

Beside the picture strip is a narrow track called the sound track which is composed of a series of light and dark strips. A tiny beam of light is focused on the strip, and the emergent light strikes a photocell, producing a varying electrical current. This current is amplified by a radio amplifier, thus operating the loud speaker. The sound track and the motion picture strip are synchronized, so that the speech or song seems to come from the picture on the screen. (Fig. 176.)

RAINBOW

One of the most beautiful of the phenomena of nature is the rainbow. Few persons have a true conception of the cause of this solar spectrum, which appears only at certain times of the day.

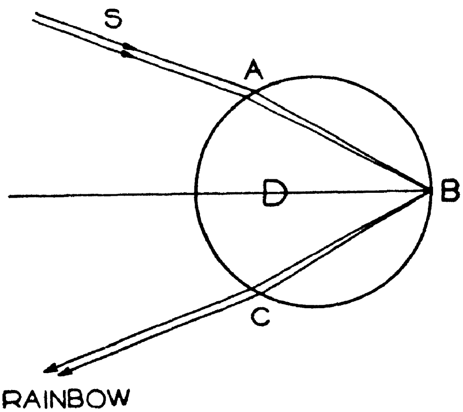


Fig. 177.—The rainbow.

Briefly, the cause is the prismatic effect of water drops. When the sun is rather low on the horizon in the afternoon, the light may be refracted and internally reflected by drops of water in the atmosphere, thus causing a rainbow to appear in the eastern sky. A rainbow can never occur in the middle of the day and rarely occurs in the morning. Let *S* (Fig. 177) represent the light coming from the sun in the west. *D* is a drop of water. The light is refracted at *A* as it enters the drop, is reflected at *B*, and is again refracted at *C* as it leaves the drop. The white light is separated

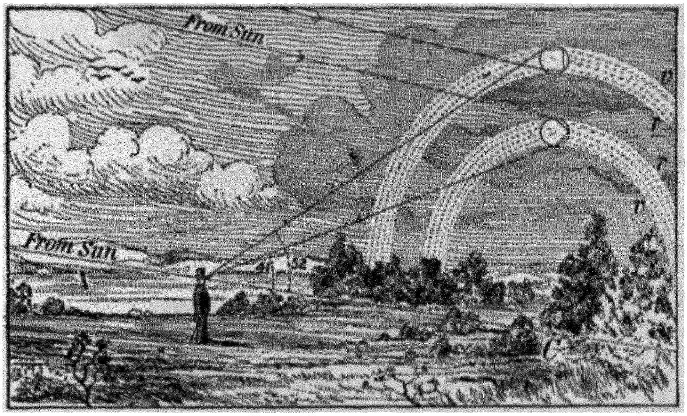


FIG. 178.—The rai m "*A Textbook of Physics*" *by Chant and Burton, courtesy Henry Holt and Co.*)

into the spectrum colors, and as the observer faces east, inclining his head at an angle of 42 degrees, he will see the red of the spectrum; at an angle of 40 degrees, he will see the violet (Fig. 178). Any spray of water such as a water fall, or the mist of a lawnsprinkler, can produce a rainbow under the proper conditions. Occasionally, there is a secondary bow with reversed colors. (See any physics text.)

ULTRA-VIOLET

The part of the electromagnetic group of radiations called ultra-violet is usually associated with the visible spectrum. The visible spectrum, extending from 8000 Ångströms to 4000 Ångströms, continues into the invisible region. Some ultra-violet

coming from the sun penetrates our atmosphere. Rays in the region of 3000 Ångströms affect the growth of the body by assist-

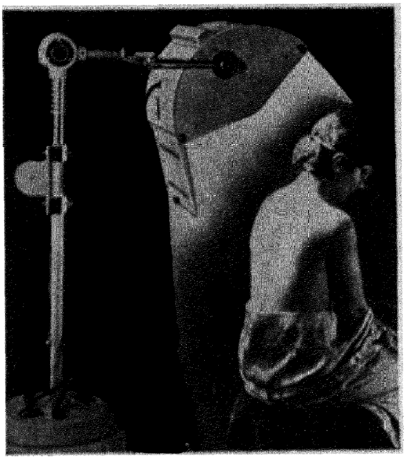


FIG. 179.—Ultra-violet rays used in producing sunburn and tan. (*Courtesy Hanovia Chemical and Mfg.* (*Co.*

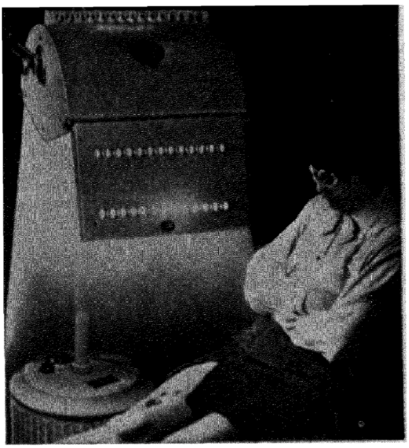


FIG. 180.—The use of short ultra-violet rays in the treatment of skin diseases. (*Courtesy Hanovia Chemical and Mfg. Co.*)

ing the process of bone calcification. These radiations have the property of causing ergosterol, which is found in such materials as cod-liver oil, cotton seed oil, and other fats, to become vitamin

D when the oil is subjected to ultra-violet for a time. Vitamin D helps the bones to absorb calcium and phosphorus, and is thus effective in the treatment of rickets. Some milk companies are subjecting their product to ultra-violet, thus producing vitamin D in the milk. This milk makes it unnecessary to give cod-liver oil to small children. The ultra-violet rays from the sun are absorbed by window glass, so that house dwellers get very little of this beneficial radiation directly from the sun and must supplement by use of cod-liver oil or the equivalent in order to secure vitamin D. The ultra-violet rays extending from 3000 to 3200 Angströms cause sunburn and tan (Fig. 179).

On the other hand, the ultra-violet in the region of 2537 Ångströms has germicidal properties. This radiation can destroy such bacteria as B typhosus, B coli, and B cholera, in a few seconds. These rays are used in the treatment of various skin diseases such as lupus* (Fig. 180). Since they can injure healthy tissue, it is essential that the skin and eyes be protected from such radiations. Some mercury and carbon lamps are dangerous, and should be used only upon the recommendation of a physician, but in most sun lamps the dangerous rays do not escape through the glass shield. Within the past few years various types of glass have been produced which permit the passage of the harmless ultra-violet. Some of these glasses are "Corex" and "Vita glass."

A very important use of ultra-violet is in the study of the fluorescence of rocks. As has been stated in Chapter 9, many rocks glow with interesting colors under ultra-violet rays. Zinc sulfide glows with a beautiful green, fluorite becomes a brilliant purple.

POLARIZED LIGHT

For many years, scientists have believed that light waves were transverse. This means that the vibrations of the medium are perpendicular to the direction of motion of the wave. If this is true, the wave can be polarized, that is, have vibrations in only one plane.

The usual demonstration experiment was a rope passing through a series of picket fences (Fig. 181). If the pickets are

* A tubercular disease of the skin.

upright, each vibration in a vertical direction can proceed through the pickets. The wave between the two fences lies in one plane and is polarized. If the pickets of the third fence are horizontal, these vibrations are stopped and no wave passes through. We must remember that we have no definite proof of the truth of the wave motion of light. Nevertheless, it has long been known that two pieces of the transparent mineral tourmaline, if placed in a certain position relative to each other, could prevent light passing through. Up to 1930, polarized light was a laboratory

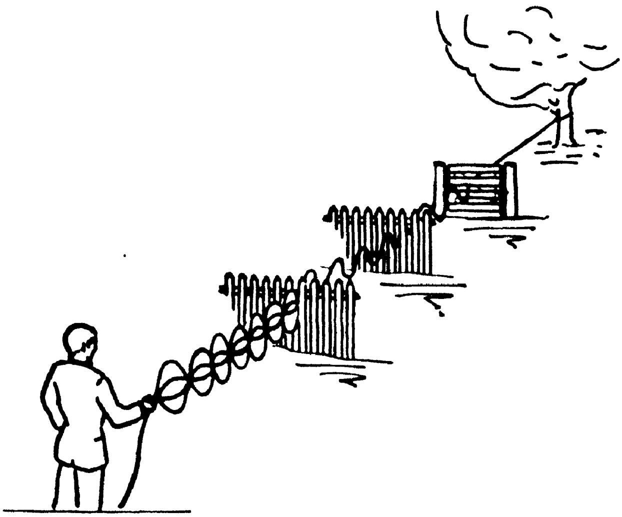


FIG. 181. A graphical drawing of the rope analogy to polarized light (*Courtesy Journal of the Franklin Institute*)

curiosity, so much so that it was not always discussed in physics courses.

For many years, scientists had known that the solution of the headlight glare problem lay in the use of polarized light. In 1930, Edwin Land invented a material called *polaroid* which has received wide publicity. The material consists of a cellulose acetate (cellophane), in which are embedded millions of submicroscopic needle-like crystals of Herapathite, all lying parallel to each other. Light passing through this material becomes polarized in one plane. Two pieces with the polarizing directions crossed, cut off the light (Fig. 182). This material is being used for one-way vision

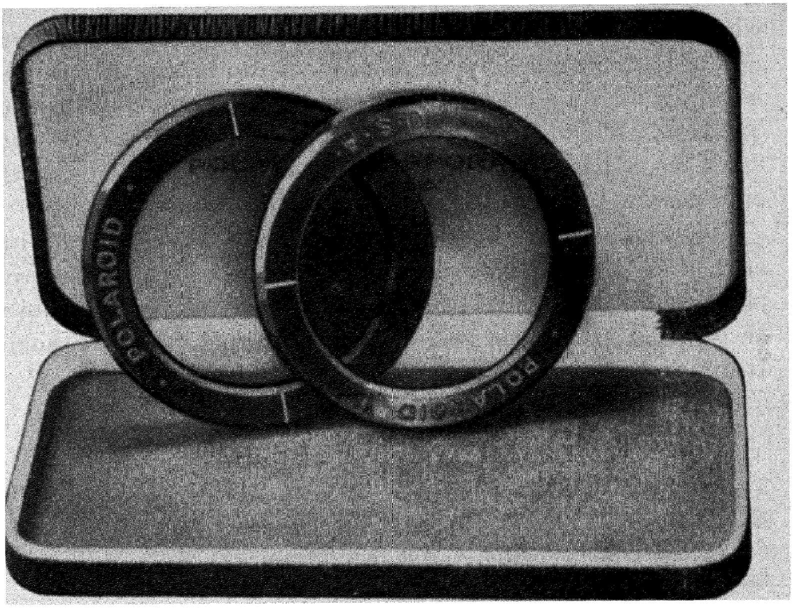


FIG. 182.—Polaroid plates crossed to show extinction of light. (*Courtesy Welch Mfg. Co.*)

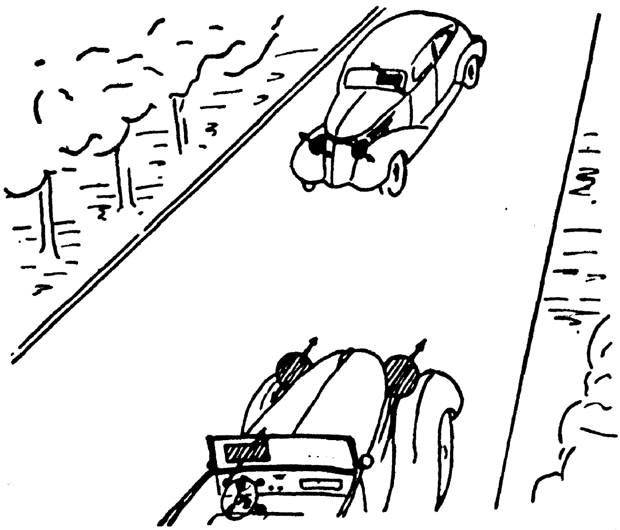


FIG. 183.—Sketch showing the method of installing Polaroid in automobiles. The arrows indicate the polarizing directions. (*Courtesy The Journal of the Franklin Institute.*)

windows, for reading lamps, for sun glasses, and for the elimination of glare from headlights. Figure 183 shows how the material is installed in an automobile. The headlight lenses and a portion of the windshield contain *polaroid.* As two cars approach each other, each has clear vision of the road, but the light of the approaching headlight is nearly cut off. There is no glare.

Modern science progresses at a breath-taking pace. Time after time obscure scientific discoveries have become a great practical importance. (The interested reader will find the subject of polaroid treated in detail in the Journal of the Franklin Institute, September 1937.)

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Luckiesh LIGHT AND HEALTH Williams and Wilkins.

PROBLEMS

1. What is the difference between candle power and intensity of illumination?
2. What is meant by the efficiency of a lamp?
3. Explain the process of taking and developing a picture
4. To what is the color of an object due?
5. What causes a rainbow?
6. What is a panchromatic film?
7. What is a diopter? A lens of 2 meters focal length has what power?
8. What is the illumination on a book when a 16 candle power lamp is 4 feet away?
9. What is meant by television?
10. Explain how the eye is corrected for errors of vision
11. What is meant by talking movies?
12. What is the difference between direct and diffuse reflection?
13. What is monochromatic light?
14. A compound microscope has an objective of magnification 40 times, and an eyepiece of magnification 15. What is the magnification of the instrument?

VISUAL AIDS

1. THE EYES OF SCIENCE—Bausch and Lomb Optical Company An excellent three reel film
2. Three films on LIGHT—Eastman Classroom films.

TOPICS

Photography.	The Rainbow	Good Lighting	Spectacles
Color.	Microscopes	Television	Polaroid.

EXPERIMENTS

1. *A study of lenses and telescopes*

Find the focal lengths and powers of the two lenses given you. Construct a telescope by using a thin lens (low power) as the objective, and the thick lens (high power) as the eyepiece

Focus the telescope on a chalk scale on the blackboard. Keeping both eyes open, view the scale through the telescope with one eye, and view the board with the other Count the number of divisions of the board scale that fit into the distance between two lines of the telescope scale. This is a measure of the magnifying power

Look at objects in the room through the model telescope and describe their appearance

Find the magnifying power of a reading telescope.

Use the thick lens as the magnifying glass and estimate the magnifying power by focusing on a small square on a sheet of paper.

2. *A study of the process of making photographs.*

Remove the back cover of the camera, replace it with a ground glass screen, and adjust the lens until you secure the sharpest image. Examine variations in the image when the stop is opened and closed. Replace the back cover, insert the film or plate, and take photographs. (If the day is dull use a time exposure or a photoflash lamp In this case it will be necessary to have the camera mounted on a tripod or table) If the day is sunny make snap shots, using different stops. Make exposures facing the sun as well as in the opposite direction.

Make up two solutions, one for developing, and the other for fixing. As a developer use any standard developing powder or liquid, and prepare the solution according to the directions on the container. Use any standard fixer and follow directions for the preparation of this solution. In a dark room, place the exposed film in the developer, and, being careful not to touch the dull surface with the fingers, allow it to remain until the image begins to penetrate through to the back (shiny surface). Remove and wash in running water. Place the negative in the fixing bath, and allow it to remain until all white

material has disappeared. Wash for ten minutes in running water. If time is limited, use alcohol as a final wash Allow the negative to dry, and make a print according to the directions on the package

3. *The compound microscope.*

Examine the microscope before making any adjustments You will find that the objective lens is marked with the magnifying power, and the numerical aperture number. The eyepiece tube is also marked with the magnifying power The product of the two magnifying powers is the magnifying power of the lens combination.

Next insert a microscope slide, for example, an amoeba, on the table and rack the microscope down carefully, watching the lens to see that it does not touch the slide and break it. When the objective is close to the slide, begin to rack the tube *upward* and look through the microscope When the object comes into view, use the slow motion rack to complete the adjustment

If you use the 4 millimeter objective, you will need to be careful to rack slowly, since the distance of the lens from the slide is about 4 millimeters (about 1/8 inch) After you are familiar with the adjustment, use a millimeter scale on the stage, and using both eyes, view the scale in the microscope and the scale outside at the same time. Measure the magnification. (For this experiment use the 16 mm. objective)

4 Make a photomicrograph of the amoeba, using the camera in conjunction with the compound microscope.

18

ENERGY AND ITS RELATION TO SOUND

"Of all noises I think music the least disagreeable."
Samuel Johnson

WE LIVE in a world of sound. Our ears are constantly making us aware of the sounds of wind, of birds, of insects, and a multitude of mechanical devices. When we clap our hands, slam a door, or pluck a violin string, energy travels in the air in the form of sound waves.

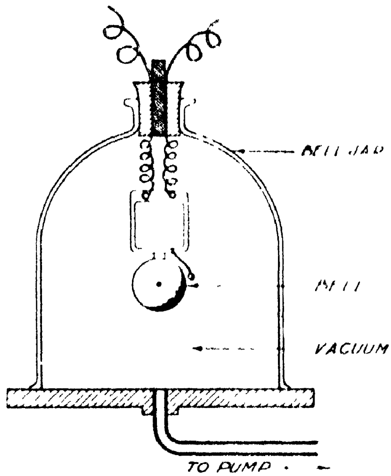

FIG. 184 A bell in a vacuum (*Bowden*)

A boy whistling or dragging a stick along a fence is producing a series of sound vibrations. If one strikes a bell or rod and immediately touches it with the finger tips, a vibration can be detected. *Sounds are produced by the vibrations of elastic objects.* These sound waves are transmitted by solids, such as steel; by liquids and by gases. Sound waves do not travel in a vacuum, as do light waves. They require material media for their propagation. (If a bell is rung in a vacuum (Fig. 184), no sound can be heard.) Moreover, they do not travel like water waves, but as a longitudinal wave. In order to understand this, imagine a row of men standing one behind the other, each man having his hands firmly braced on the shoulders of the man in front of him. If a bystander gives the rear man a push forward, each man in the row will be pushed, so that he leans forward, although none of the men will actually move out of their positions. A longitudinal wave has passed

through the group. The men were first pressed together, and as they regained their balance they spread apart.

Another example is a field of ripened wheat. A breeze blows the heads over and a wave travels in the field. The stalks vibrate to and fro as the longitudinal wave passes through the field. In like manner, the air particles move back and forth as the sound

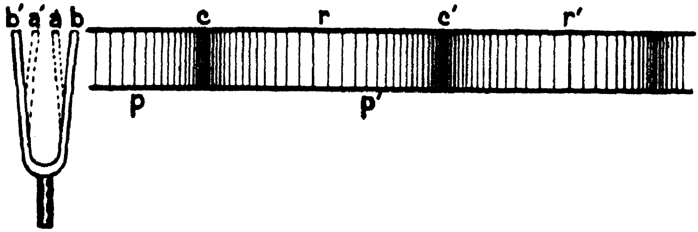

FIG. 185.—Compressional waves in a pipe produced by a vibrating tuning fork. c and c' represent compressions. r and r' are rarefactions. (*Foley.*)

waves pass through the atmosphere. Such waves are called compressional waves, because the air is first compressed and then released from this pressure. In Fig. 185, the fork prong at position *b* sends a compressional wave into the pipe which is shown at *c*. The fork at *a* forms the rarefaction *r*. The distance from *c* to *c'*

FIG. 186.—Beats produced by two tuning forks which have a slightly different pitch. (*Weld and Palmer.*)

is the wave length of the sound wave. Figure 186 shows graphically the action of two tuning forks in producing beats. A stretched piano wire set into vibration by the hammer of a piano, sends out compressional waves into the air. These waves upon striking the ear produce the sensation known as sound. Two good examples of compressional waves are thunder and the explosion

of a firecracker. The sudden expansion of the air compresses the adjacent layers which in turn expand. These compressions and rarefactions travel through the air.

If the number of vibrations of the elastic body, for example, a tuning fork, is as great as 30, the ear recognizes the wave motion as a sound. Any number of vibrations less than 30 is usually not considered an audible sound, although some organ makers use a pipe sounding 16 vibrations per second. The ear recognizes as musical tones, vibrations as high as 4000 per second, and can detect sounds up to 20,000 vibrations per second (Fig. 187). These

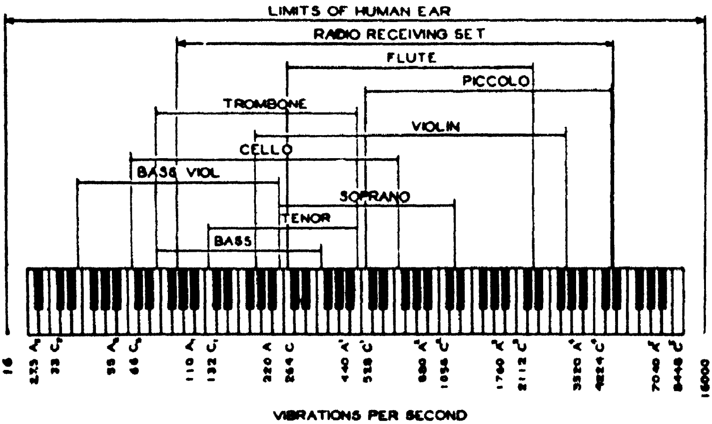

FIG. 187.—Pitch range of various musical instruments.

high notes sound like squeaks and are not considered musical. *The number of vibrations per second is the pitch of the tone.*

As a rule, young persons have a keener sense of pitch than elderly people. There are mechanical devices which can register high pitched notes that are inaudible to the human ear. One of these devices is the whistling flame.

To produce a whistling flame, a glass tube is drawn down to a tip with a bore of about one millimeter (Fig. 188). Gas is passed through the tube and the pressure adjusted so that the gas flame is just on the point of flaring. Usually, such a flame will be about one foot high. As the high pitched whistle is sounded, or a bunch of keys is rattled, the flame will "duck" as the compressional

waves pass over the outlet. If the gas pressure is low, a booster tank may be necessary.

ULTRASONIC WAVES

During the past few years, compressional waves with a pitch of the order of one million have been produced by causing a piece of quartz to vibrate in a liquid. This is called the piezo-electric effect and the vibrating plate can be operated so as to produce waves of a very high pitch. The piece of quartz, cut with its thickness parallel to an optic axis and perpendicular to an electric axis, is placed between two metal plates. A high potential is connected to the plates, setting up a potential difference which causes the quartz to expand in one direction and to contract in another. By using a rapidly alternating potential difference, we can produce rapid expansions and contractions of the quartz. The vibrations set up supersonic waves in the liquid above the quartz. Some interesting properties of such waves are the destruction of all types of living matter, including bacteria, which may be in the liquid. High frequency sounds are now used to sterilize milk, age whiskey, improve the quality of photographic films, precipitate smoke in chimneys, and assist in mixing mayonnaise.

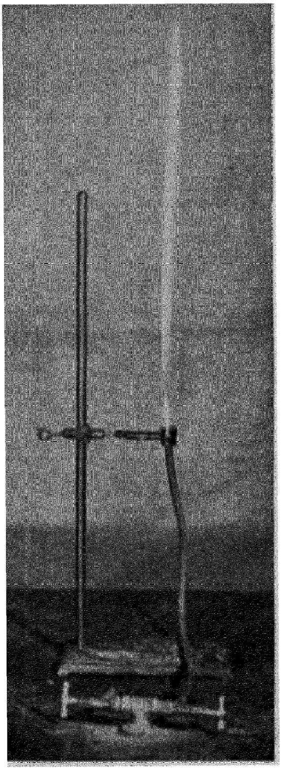

FIG. 188. The whistling flame. If a high pitched note is sounded in the vicinity of the flame, the flame will "duck."

SOUND WAVES

Sound waves travel much more rapidly in solids and in liquids than in gases. The speed in air at ordinary temperatures is about 1100 feet per second. Sound waves may be reflected and focused by curved surfaces. There are several whispering galleries

in the world caused by such an effect. Some of these are the Hall of Statues in the Capitol at Washington, the Mormon Tabernacle, and St. Paul's in London. A word spoken in a whisper at one point can be clearly heard at a distant point of the circular room.

THE EAR

We do not know just how we hear. There are several theories of hearing, each of which is rather unsatisfactory. The ear (Fig.

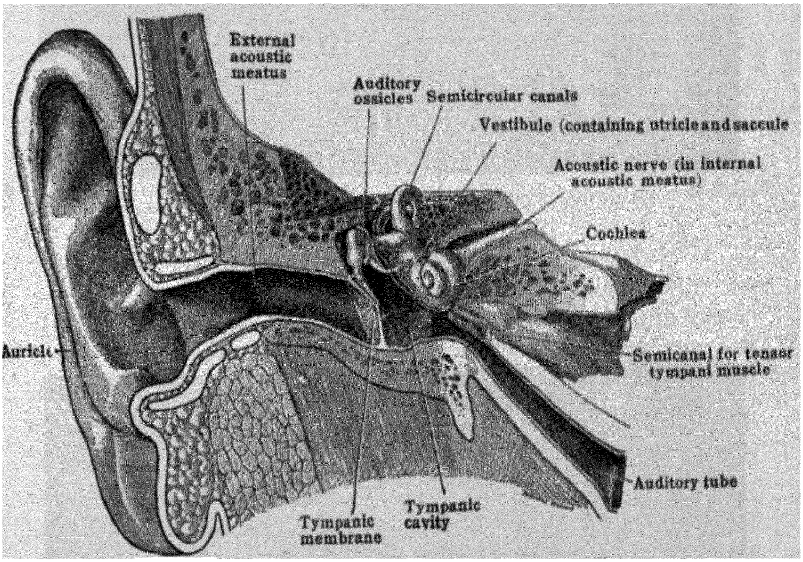

Fig. 189.—The ear. (*Morris' "Human Anatomy."*)

189), consists of a passage (meatus) about one inch deep, which ends at the drum (tympanic membrane). Inside the membrane is a cavity, the drum cavity. In this cavity are three tiny bones: hammer, anvil, and stirrup. The handle of the hammer is attached to the membrane and the base of the stirrup touches an inner membrane (oval window). In the inner ear is the cochlea, a spiral tube shaped like a snail shell. The cochlea contains two liquids, the perilymph, and the endolymph. Associated with the cochlea is the organ of Corti and a basilar membrane. The outer drum and the bones cause the oval window to vibrate, which in turn causes vibrations of the inner ear liquids. These moving

liquids excite sensory hair cells in the basilar membrane and, in some unexplained manner, change the mechanical impulses into nerve impulses.

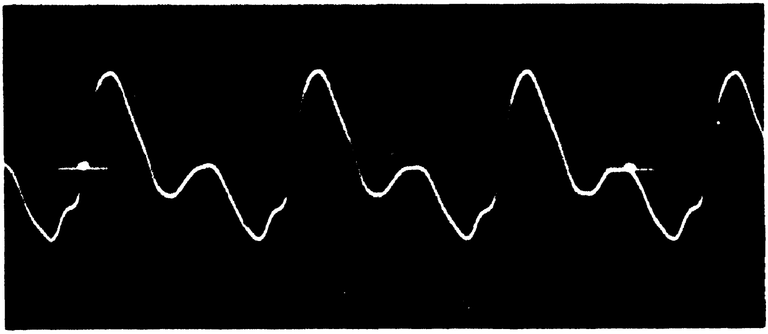

FIG. 190.—Photographic record of sound produced by a flute. (*Weld and Palmer.*)

The ear is so sensitive that it can detect a sound wave whose power is less than a billionth of a watt, a quantity so small that we cannot appreciate it. It can also withstand the loudness of a boiler

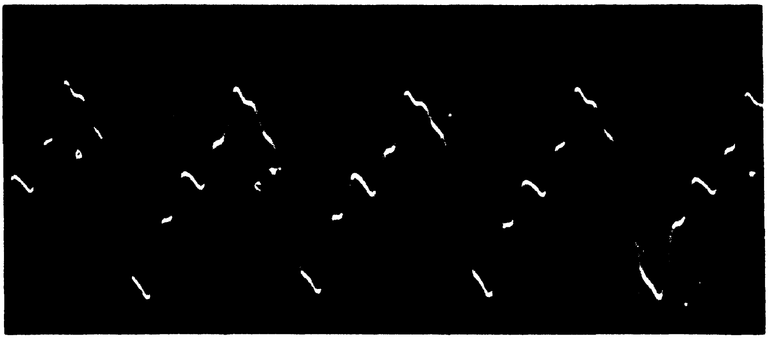

FIG. 191.—Photographic record of musical sound produced by a violin. (*Weld and Palmer.*)

shop. On the musical side, the ear can distinguish a change of pitch of two or three vibrations per second. Scientists have set up a scale of loudness for which they use the unit named *decibel.*

Quietly rustling leaves at 5 feet	20 decibels
A typewriter in operation at 5 feet	50 decibels
An ordinary human voice at 3 feet	60 decibels

Street traffic at 50 feet	70 decibels
Riveter at 2 feet	100 decibels
Painful noise	120 decibels

Most sounds do not consist of one frequency alone, but are a composite of several modes of vibration. The *composite sound determines the quality of a tone*. If a piano string is sounding 440 vibrations per second (fundamental), it will sound several multiple frequencies simultaneously; 880, 1760. These are called *harmonics* or *overtones*. Each musical instrument has its own peculiar set of overtones which give it its individual quality. Figures 190 and 191 show photographic records of the waves from a flute and a violin. It is evident that the shapes of the waves are different in the two cases. The shapes of the waves from two instruments show that the quality of the tones differ, even though the same selection is being played on both.

ACOUSTICS OF AUDITORIUMS

One of the most important developments in the study of sound is the subject of architectural acoustics. The word, acoustics, means hearing. In a room with good acoustics, the auditor with average hearing should easily hear and enjoy words and music, provided they are originally clear and distinct. Bad acoustics in an auditorium may be due to echoes, reverberations, or dead spots. When a sound is produced in a room, it must be absorbed by the walls, floors, and objects in the room, or it must escape through doors and windows. Otherwise, it will be reflected. If the room has hard walls, the sound will be reflected from wall to wall, thus causing echoes and reverberations. Up until 1900, the improvement of auditoriums was a hit or miss experiment. Dr. Sabine of Harvard, after an elaborate series of experiments, set up certain laws which should govern the construction of rooms if they are to have good acoustics. Echoes are caused by the sound being reflected from a wall in such a manner that the hearer may hear a word twice, once directly and once by reflection. Sometimes, the condition is so bad that the listener hears two words at the same time, because of the fact that the echo of a word

mingles with the following word coming directly from the speaker. The result is a jumble of sound that makes listening very difficult. Figure 192 represents the auditorium of the University of Illinois. In this room, the echoes were so bad that speakers refused to appear on the platform. The drawing shows the direc-

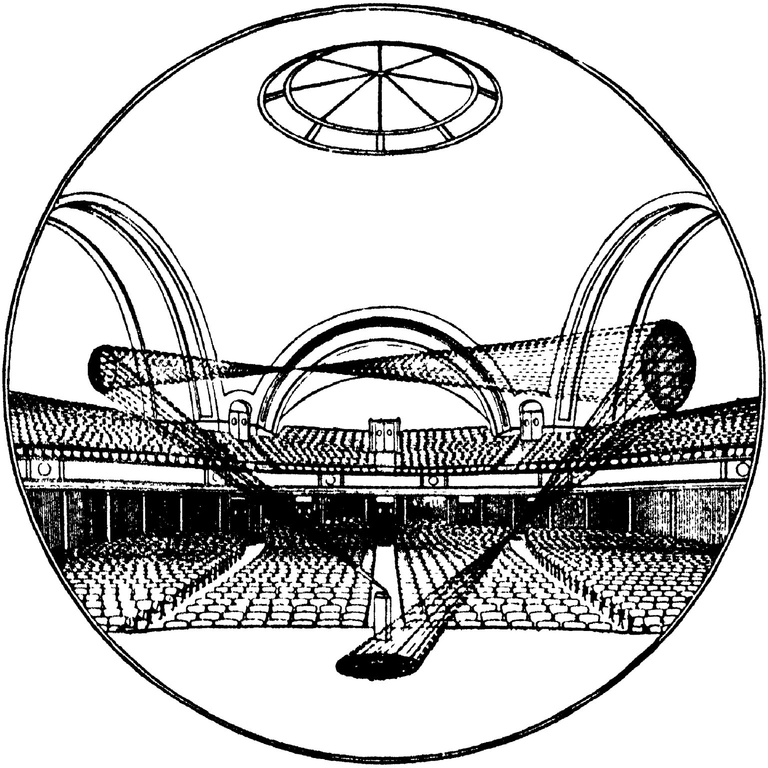

FIG. 192.—Drawing showing how an echo is formed on the stage by two reflections. Such an auditorium has bad stage acoustics. (*Reprinted by permission from Watson's "Acoustics of Buildings," published by John Wiley and Sons, Inc.*)

tions of reflection of sound. The room was improved by false walls and concealed curtains, which absorbed the greater portion of the sound that would have been otherwise reflected.

Sometimes, owing to reflections, there are dead spots in a room. At such places, the auditors hear very little. *Reverberations* mean that the sound travels from wall to wall around the room,

making the room noisy and causing the speech to be muffled. In such a room, the sound may be audible for a few seconds after the source of sound is stopped. This interval is called reverberation time. The listener has the sensation of a roar of sound. A familiar example of excessive reverberation is the sound of footsteps of a person walking about in an empty house. The room seems to be full of people walking about. On the other hand, if there is no reverberation, one has the sense of deadness of the

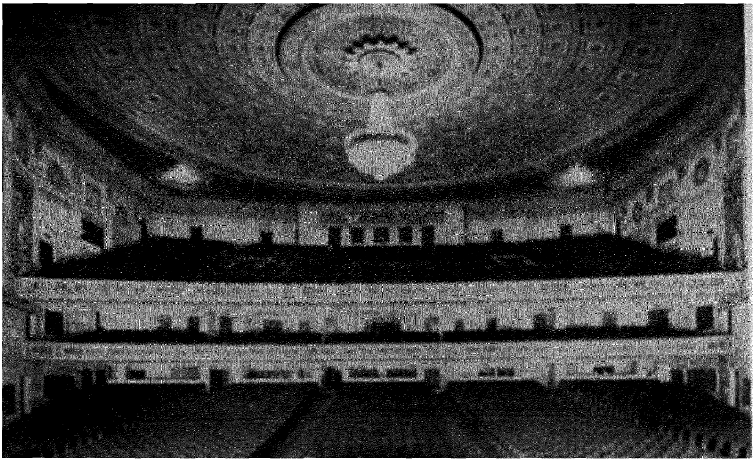

FIG. 193.—The Eastman Theater, Rochester N.Y. The acoustics of this auditorium are excellent. (*From Watson's "Acoustics of Buildings," John Wiley and Sons, Inc., Publishers.*)

sound. It is estimated that reverberation ought to last for at least one-tenth of a second for best sound effects.

There are several methods for remedying bad acoustics. As a rule, a circular room is unsatisfactory. Rectangular rooms with walls and ceilings of the proper material are best (Fig. 193). Bad conditions may be remedied by hanging draperies, using rugs on the floors, installing false ceilings, and constructing the walls of absorbing materials. There are many materials such as wall board and special plasters which are designed for the purpose of absorbing sound. The acoustical correction of an auditorium is a task for an expert (Figs. 194, 195 and 196).

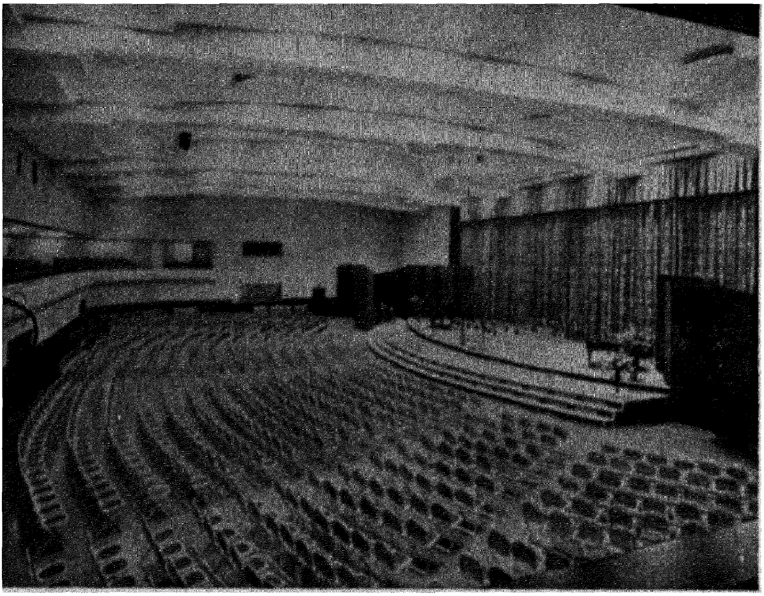

FIG. 194.—Radio City Music Hall. This great auditorium has excellent acoustical properties due to the special treatment of the walls and ceiling. (*Courtesy Johns-Manville.*)

FIG. 195.—The photograph shows the method of sound-proofing the floor of a dance hall. (*Courtesy Johns-Manville.*)

PRACTICAL APPLICATIONS OF ECHOES

Although echoes are very disturbing in auditoriums, they have been found useful in many commercial operations. One of the modern uses of echoes is the study of ocean deeps (see p. 94). A wave of sound is sent down into the water, the time required for

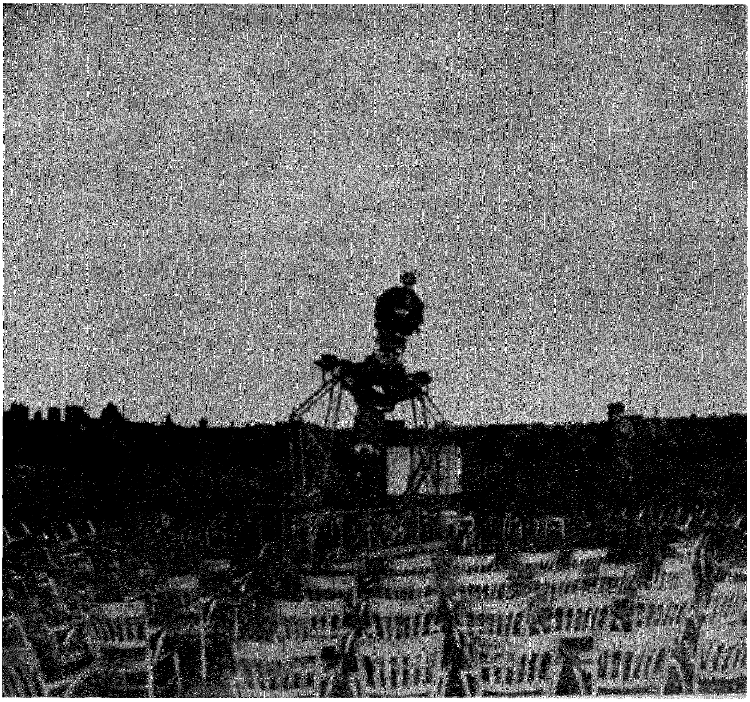

FIG. 196.—The Fels Planetarium of the Franklin Institute. The acoustical treatment of the hemispherical dome made this an excellent room for hearing. (*Courtesy Johns-Manville.*)

the sound to reach the bottom and return being noted. Since we know that the speed of sound in water is 1440 meters per second, the great deeps can be studied by a moving vessel.

NOISE AND MUSIC

We divide sound into noise and music. As a rule, we mean by noise a succession of irregular, unsteady sounds which, being

discordant, are unpleasant to the ear. Some examples are, a wagon rattling over rough pavement, the squeals of animals in pain, or the crashing of colliding material. A boy dragging a stick over a picket fence is producing a vibration each time he strikes the picket. If he strikes 30 pickets per second in regular order, he produces a musical note but, if he strikes one and then another in no regular interval of time, he is said to be producing only noise. If all of a set of wooden sticks tuned to a musical scale are dropped at once, the effect is a noise, but if certain sticks are dropped in a regular order, we have a series of musical tones.

There are certain combinations of tones which are very pleasing to the human ear. Occidental music is based on the *diatonic* scale of pitch. It is probable that in ancient times, certain singing tones were found to be more pleasant than others. In this way, the scale arose from the folk songs of the people. By agreement among musicians the standard pitch of this scale is set with *A* at *440 vibrations per second*. From this note all others are tuned.

MAJOR SCALE. There are certain combinations of frequencies which are pleasing to the ear. It has been found that notes bearing relations to each other of 9 to 8, 16 to 15, and 10 to 9, form a scale that is musical. For instance, the *major* scale in the key of *C* is as follows:

C		D		E		F		G		A		B		C
264		297		330		352		396		440		495		528
	$9/8$		$10/9$		$16/15$		$9/8$		$10/9$		$9/8$		$16/15$	

All major diatonic scales, no matter what the key, have the same frequency relations. The second note must be $9/8$ of the first, the third $10/9$ of the second as indicated above. There are moreover, certain combinations of these frequencies which are pleasant to the ear. For instance middle C (264), and C′ (528) may be played together, thus forming the octave. On the other hand, C (264) and D (297) are never played together because the effect is unpleasant. The various combinations of pitch which are pleasant constitute the musical selection. Some peoples, such as the Chinese, use in music a different combination of tones which sound strange to the western ear.

BEATS

In order to explain why the diatonic scale is pleasing, it is necessary to discuss *beats*. If, for example, two people are walking side by side, one taking 30 steps per minute, and the other 29 steps in the same time: once each minute, both will step at the same time. The effect will be an increased sound, a beat.

If two banjo strings are supposed to be tuned to the same pitch, for example, 400 vibrations per second, and if we hear two beats during the second when both strings are vibrating, we know that there is a difference in pitch of two vibrations per second between the two strings. Many piano tuners adjust the pitch by counting beats between adjacent strings which are being tuned. These slow beats are unpleasant to the ear and are avoided in music.

CONSONANCE. Referring to our discussion of the musical scale, it will be noted that in the diatonic scale the notes differ by as few as 22 vibrations per second (E and F), and by as many as 55 (A and B). In general, we may state that the intervals average 30 vibrations per second. It is probable that two notes such as C (264), and E (330) are pleasing because they have a difference of 66 vibrations per second. In general, a large number of beats per second is not unpleasant. This may be a partial explanation of our musical discrimination of pleasing tone.

The consonant intervals are: octave 1:2, fifth 2:3, fourth 3:4, major third 4:5, minor third 5:6, major sixth 3:5, minor sixth 5:8.

MINOR SCALE. In the *minor* scale the notes bear the following relation to each other: $9/8$, $16/15$, $10/9$, $9/8$, $16/15$, $9/8$, $10/9$. It will be noted that only the ratios of $10/9$ and $16/15$ have been interchanged. This scale is less pleasing than the major and is used in musical selections where sadness and gloom are represented.

Actually it is not feasible to use the exact pitch of the diatonic scale in designing the strings of a piano. It would be necessary to have 70 keys in each octave, or a total of about 400 keys for the piano keyboard. To avoid this difficulty the tempered scale is used. By sacrificing exact frequency it is possible to make a scale

that is not unpleasant. but which can be manipulated by the piano performer.

MUSICAL INSTRUMENTS

One of the simplest of musical instruments is the tuning fork. This is a steel bar bent into the form of a U. Such a fork set into vibration sends out a regular succession of waves of one frequency, having no harmonics. For this reason tuning forks are used as standards of pitch. They are not desirable musical instruments because they have no beauty of tone.

Musical instruments are divided into three classes: the strings, the percussions, and the wind instruments.

The strings are instruments which produce sound vibrations by means of stretched strings of gut or wire, set into vibration by a hammer (piano), a bow (violin), or the hand (banjo). Some examples of wind instruments are the organ pipe, flute, clarinet, cornet, trombone, and the human voice. The percussion instruments include the drum, the xylophone, the bell, and the marimba. (The marimba is one of the newest of percussion instruments. It is of African origin.)

The instruments containing strings have, in addition to the strings, a sounding board or resonator. As the string is set into vibration, it transmits energy to the sounding board, setting it into vibration. Most of the sound comes from the resonator and not from the strings. We are all familiar with stories of the violins produced by Stradivarius. The beauty of the tones produced by his violins depends upon the care with which the body of the violin was constructed. A Stradivarius is probably the most costly instrument in use at the present time.

In the case of the pipes, such as the clarinet and organ pipe, the lips or a reed set up vibrations in the pipe. The human voice is an instrument having two vocal cords which are set into vibration as the air passes through the openings. The lungs force air upward through the trachea and larnyx into the mouth and nose. The cords, which are triangular, act like reeds of an organ (Fig. 197). The rate of vibration of the cords is controlled by the muscles of the larynx. The nose, mouth, and throat, act as the

resonators for the cords, so that, by varying the shape of the mouth, we can change the pitch and the quality of the tone. The trained singer has learned to utilize all the cavities of the head in order to produce pleasing tones.

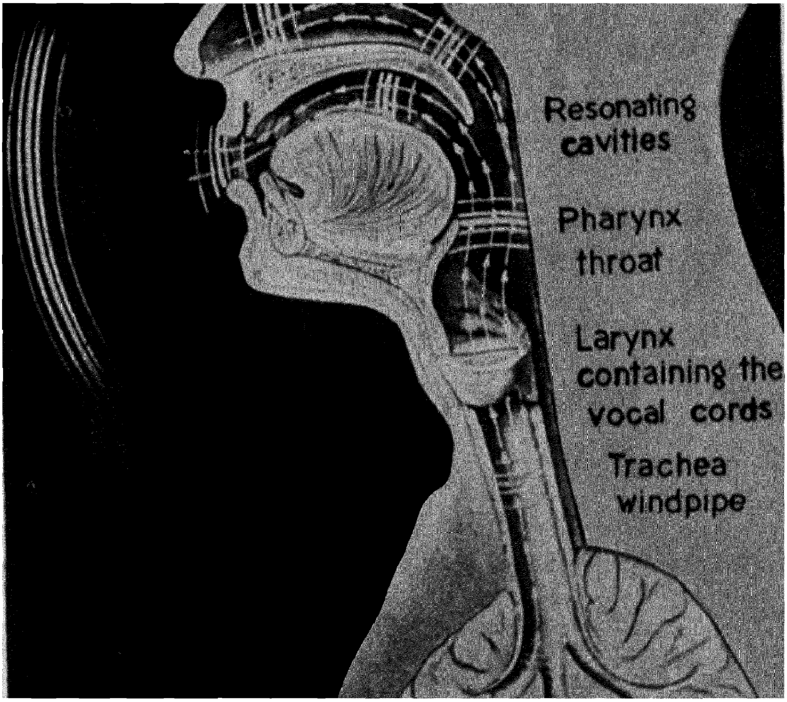

FIG. 197.—The mechanism of speech. The air from the lungs passes through the larynx and sets the vocal cords into motion. The cavities of the nose and throat act as resonators, enhancing the sound. (*From the educational picture "Sound Waves and Their Sources," By H. I. Schleshinger and H. B. Lemon, produced by Erpi Picture Consultants and the University of Chicago Press.*)

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PROBLEMS

1. What is pitch? What is quality?
2. What is meant by music?
3. Describe the three general types of musical instruments.
4. What is meant by the term, acoustics?
5. Give two modern applications of sound.
6. Distinguish between noise and music.
7. How can we improve a room having a bad echo?
8. How do we hear?
9. How do we speak?
10. What is a diatonic scale?
11. Write the major scale of D (297).

TOPICS

Chinese Music.
Carillons.
The Player Piano.
The Marimba.
Ultrasonic Waves (Scientific American 1932).
Phonograph.
The Theremin.
Acoustics.

EXPERIMENTS

1. Construct a whistling flame and study its action.

2. Sound a flute or a xylophone bar in an auditorium. Investigate the echoes and search for dead spots. Time the reverberations.

3. Using a Galton whistle, study the pitch perception limits of the various members of the class.

4. Have some one demonstrate the methods for changing the pitch of musical instruments.

5. If an oscillograph or an oscilloscope is available, connect a microphone to the instrument and have members of the class sing notes into the microphone. Study the wave form of the different voices. Use also a tuning fork and an organ pipe. The instrument will illustrate both pitch and quality. (There are now on the market inexpensive oscillographs which should be a part of the equipment of every general science course.)

19
ELECTRICITY AND MAGNETISM

"Too like the lightning, which doth cease to be
Ere one can say, 'It lightens.'"
Shakespeare

IT IS quite probable that of all types of energy, electrical energy has contributed most to the progress and convenience of mankind. Although we live in an electrical age, riding on electric trains, warmed by electrical heat, talking by means of the telephone, seeing by television, few persons know anything about the fundamental principles governing this great servant to the human race. In the past forty years we have progressed from oil lamps to tungsten gas-filled light bulbs, from horse drawn vehicles to automobiles made possible by spark coils and storage batteries. The dentist uses an electric drill, the medical man uses X-rays and ultra-violet rays, the surgeon often uses an electric tool (cautery) instead of a scalpel, the muezzin of a mosque calls the faithful to prayer by a microphone and loud speaker.

One of the reasons for this universal use is the ease with which electrical energy can be generated and transmitted. By means of generators, transformers, and wires, the energy can be silently and cheaply distributed to distant points. In the present chapter, we shall try to present some of the fundamental principles so that the reader may gain some familiarity with this form of energy. In a subsequent chapter, we shall describe some of the applications of electricity in everyday life.

ELECTRICAL UNITS

In beginning a study of the manifestations of electrical energy, it is necessary to define and explain some terms that will be used. The socket of an electric light bulb is sometimes marked 250 volts, 660 watts. These numbers mean that the socket can be safely used on wires in which the voltage does not exceed 250, and

in which the power consumption does not exceed 660 watts. Under ordinary conditions the electric light wires in the house are at a potential difference of 120 volts. The potential difference is a measure of the potential energy, somewhat as the difference of level between the reservoir and the faucet is a measure of the potential energy of the water. By means of a pump (Fig. 198) water is raised to a higher level on one side of the tank. There is a difference of potential between (*A*) and (*B*). If (*C*) is opened, water flows from (*A*) into (*B*), and the pump must again raise the level in (*A*) if the stream of water is to continue. In like manner, an electron pump must maintain a difference of potential. This electron pump may be a cell, a generator, a thermocouple, or a photocell.

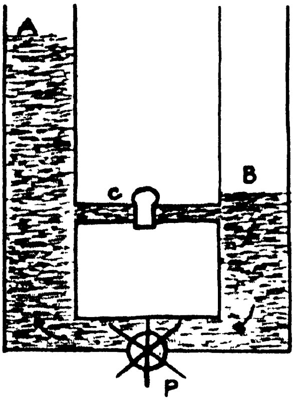

FIG. 198.—Pump P is analogous to the cell which sets up a difference of potential.

As the switch is turned on at the socket in which there is a 60 watt lamp, the 120 volt potential difference causes a current of ½ ampere to flow through the lamp. This follows from the definition of the watt:

Watts equals volts times amperes
60 equals 120 × ½

Because the lamp requires ½ ampere to light up brilliantly, it needs a 120 volt potential difference to give the proper illumination. A 6 volt storage battery will not light the lamp, since the resistance of the lamp is too high for the lamp to be operated with a 6 volt battery. The 60 watt lamp contains a fine tungsten filament which has a resistance of 240 ohms. These various facts are expressed by the fundamental law of electricity discovered in 1826 by George Simon Ohm, a German scientist. Ohm's law states that ***the current in amperes equals the potential difference in volts divided by the resistance in ohms.***

$$A = \frac{V}{O}$$

These three terms are interdependent, and in order to describe any electrical apparatus all three must be considered. In the case

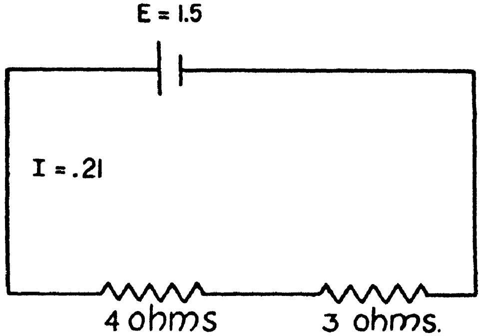

FIG. 199.

of the lamp just described, ½ ampere equals 120 volts divided by 240 ohms. Using the analogy of water, the height of the water in the standpipe above the faucet may be compared to the potential difference; the number of quarts of water flowing out of the faucet per second is analogous to the current; the size of the pipe bears a resemblance to the resistance.

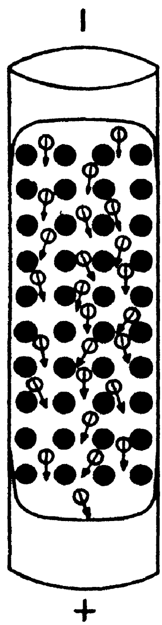

FIG. 200.

Let us apply the law to a problem: In the complete circuit (Fig. 199), the cell supplies a potential difference of 1.5 volts to two resistances of 4 and 3 ohms in series.* The current

$$I = \frac{1.5}{7} = .21 \text{ amperes.}$$

In order to interpret the meaning of *electrical current*, we shall use an imaginary experiment. Let us assume that we have the power of seeing the individual atoms of a copper wire (Fig. 200). Since the temperature of the wire is above the absolute zero, the atoms will be in motion, jostling each other as they move about. In addition, we shall notice that there are some free electrons in the wire which, owing to their kinetic energy, move about like gas molecules. These electrons collide with the atoms and the result is a continual state of irregular motion. If we now connect

* The internal resistance of the cell is neglected.

a dry cell or some other source of potential difference to the wire, the electrons being negative tend to drift toward the positive pole since a positive pole attracts electrons. This electron drift is the current, and we might define the *current as the number of electrons passing a point in the wire per second.* The cell may be said to pump the electrons through the wire.

As another analogy to *electrical current*, we might consider the current in a stream of water. *By current we mean the number of gallons of water passing a point each second.* If there are no tributaries, the same amount of water will pass all points of the stream each second. Likewise, the current in a series circuit is the same at all points. The current flows in the stream because the source is at a higher level than the mouth. The friction of the banks and bed is analogous to electrical resistance.

When the copper wire is replaced by an iron wire of the same size, the number of electrons passing a point in the wire each second will be less, although the potential difference remains the same. Apparently there is more hindrance to electron motion in the iron wire than in the copper one. *Resistance is the measure of the hindrance that materials offer to the passage of electrical current.* The unit of resistance is the *ohm.* As we measure the resistance of various metals of the same size and length, we find that some metals such as silver and copper have a low resistance (they are good conductors of electricity), while other metals such as iron, nickel, and many alloys have high resistances. The high resistance of these materials is utilized in the manufacture of heating devices such as the flat iron and the toaster. In the toaster, an electrical current of 5 amperes at a potential difference of 120 volts flows through the coils. The power utilized by such a toaster is 600 watts. By comparison, the power of a flat iron is 550 watts, of a heater 1000 watts, and of the average radio about 100 watts.

The amount of heat generated per second depends both on the resistance and on the current.

$$\text{calories/second} = .24I^2R$$

I is the current in amperes, and R is the resistance in ohms. In the toaster just described, calories/second $= .24 \times 5^2 \times 24 = 144.$

ENERGY. We pay for the electrical energy used in the home. This energy is expressed by the units *watt-hour*, and *kilowatt-hour*. A 60 watt lamp burning for one hour uses 60 watt-hours of energy. If it burns for 10 hours, it consumes 600 watt-hours or $^6/_{10}$ kilowatt-hour, abbreviated to K.W.H. On our lighting bill, the cost is calculated per kilowatt-hour. For example, at a rate of 10 cents per K.W.H. it will cost 30 cents to burn a 60 watt lamp for 50 hours, 3 K.W.H. having been used.

POWER OF SOME COMMON DEVICES

Electric iron	550 watts
Toaster	500 watts
Washing machine	300 watts
Electric range	3000 watts
Water heater	2500 watts
Average radio	100 watts
Refrigerator	100 watts

(These are average values)

FUSES. Referring again to Ohm's law, we note that, for constant voltage, as the resistance is decreased the current increases. Should the two terminals of a socket be connected (short circuited) by a wire of low resistance instead of a lamp, or should the two terminals of an extension cord touch in the plug or along the cord, a large current would flow and might damage the house wiring. In order to prevent such injury, fuses are placed in a fuse box in the circuit. This fuse is a piece of lead wire so made that the wire melts when the current exceeds a certain safe value. Since this is a safety device, neither pennies nor copper wires should ever replace the fuse plugs. Disregard of this precaution may cause fire or serious damage. On the other hand, there is no cause for alarm if the fuse does melt since the circuit has been broken and no further damage will result.

SAFETY PRECAUTIONS

Persons who are ignorant of the principles of electricity are likely to be either of two types: timid and afraid of electrical apparatus, or bold and careless. It is important to understand that if certain principles are observed, the house wiring is not dangerous. The potential difference of 120 volts is usually harm-

less to the body because of the high resistance of the skin when dry. The resistance of the body between dry hands averages about 30,000 ohms. If we divide 120 by 30,000 we find that only a small current (.004 ampere) will flow through the body even though one wire is in each hand. The only effect will be an unpleasant shock. It is estimated that a dangerous body current is about $\frac{1}{10}$ ampere. The current is the factor that causes injury;

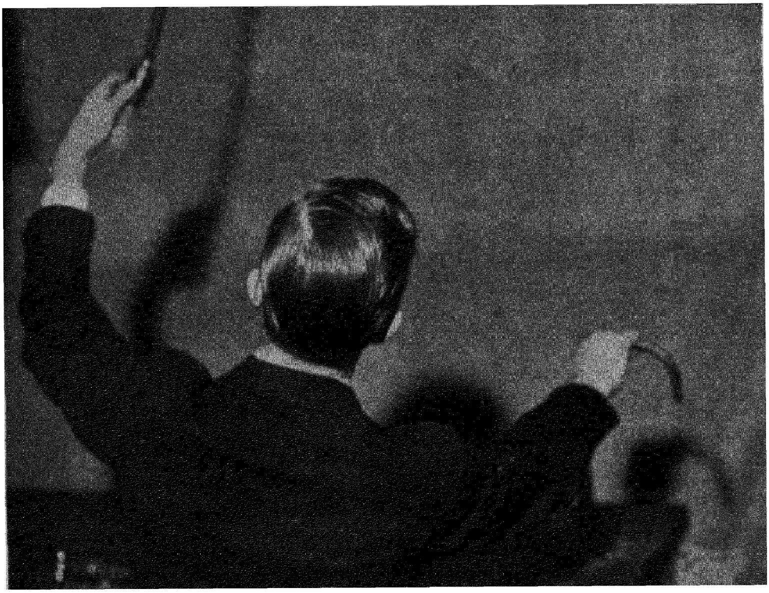

FIG. 201.—The photograph illustrates one hand touching an electric light socket while the other touches a water pipe. This is dangerous owing to the fact that current may flow from the socket through the body to the ground.

such newspaper statements as "2000 volts coursed through the body" are unscientific.

However, should a person standing on a wet floor or sitting in a bath tub grasp a poorly protected socket, a large current might travel from the hand through the body to the ground (Fig. 201), because of the low resistance of the wet body. This would cause serious shock.* For this reason, sockets should never

* Electrical shock stops respiration. For this reason resuscitation is the treatment used.

be placed in a bathroom near bowl or tub. A person using a washer on a cement floor should exercise great care that the wires are well insulated. A good socket is not a source of danger, but old sockets are often not well protected and should be replaced. Because of the low resistance of the skin of children, they should be taught to avoid playing with electrical devices.

STATIC ELECTRICITY

On p. 186, the experiment of rubbing a rubber rod with fur was described. As the fur is rubbed over the surface of the rubber or amber, some of the electrons will be removed from the fur and will cling to the rubber surface, thus giving the rubber molecules more than the normal number of electrons. This means that the rubber has a negative charge. The fur, having lost some of its electrons, is left positively charged. The charges held on *insulators* such as rubber, fur, wax, glass, sulphur, and amber are called *static* or *stationary charges*. These charges were studied in very early times. Cleopatra is said to have remarked that amber beads attracted the silk threads of her gown. In fact, the word electricity comes from the Greek word *elektron* meaning amber. Benjamin Franklin studied these static charges extensively and constructed machines by which he was able to produce static charges in large quantities. In order to prove that the electricity of lightning was of the same type as the electricity of a rubber rod, he flew a kite into a thunderstorm cloud and collected static charges from the cloud (Fig. 202). These charges had exactly the same properties as the well known static charges. Franklin took great risks, as we now know, since a charge from a cloud might have caused his death. A Russian scientist was killed while repeating the experiment.

In contrast to the *insulators*, there is another class of materials, principally the metals, upon which charges will not remain. If a copper rod is held in the hand and rubbed with fur, no charge will be found. Such substances are called *conductors*. While studying these materials, Volta (an Italian scientist) placed a copper coin and a gold coin on his tongue and touched the edges of the two coins together. The result was a feeble shock.

Following this he built a pile of plates, alternately zinc and copper separated by cloth soaked in salt water. He found that he could produce electrical charges from the plates and that by connecting the two outside plates, one zinc and the other copper, by a wire a spark was formed and the wire became hot. Here was the first device for producing a continuous stream of electrons in a wire: *an electric current.*

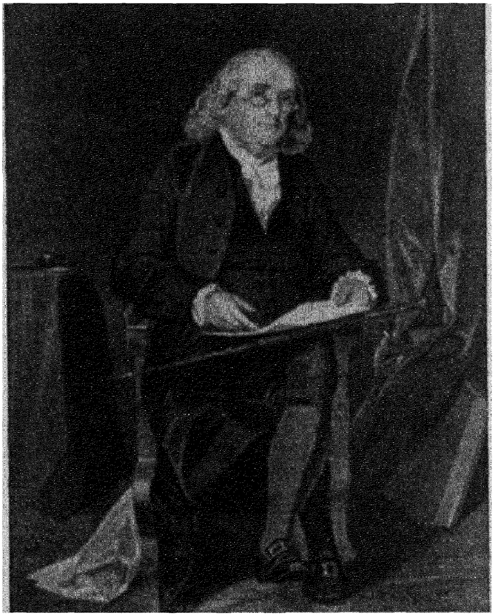

FIG. 202.—Benjamin Franklin (1706–1790). Statesman, philosopher and scientist. Studied electricity; invented the lightning rod. (*Science Service.*)

One can also show the presence of an electrical current by holding a charged rubber rod near the ear or finger. The resulting spark is a flow of electrons to the body.

THE DRY CELL

This cell, called "dry" because it is sealed so that the paste cannot escape, is a type of electron pump (Fig. 203). A zinc cup is filled with ammonium chloride (sal ammoniac) paste. In the center of the cup is a carbon rod. The ammonium chloride

dissociates into ions (see p. 356) and, as a result of this dissociation, the carbon rod acquires a positive charge (too few electrons) and the zinc cup a negative charge. A difference of potential of 1.5 volts is set up in the cell. The zinc is changed by chemical action into zinc chloride. When the zinc is exhausted, the cell is worn out and must be discarded. Such a cell is useful in operations where electrical current is needed for a short time. The *dry cell transforms chemical energy into electrical energy.*

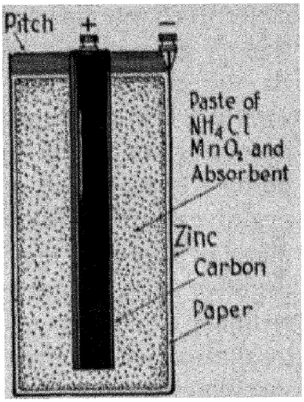

FIG. 203.—The dry cell. (*Foley.*)

STORAGE CELL

Storage cells are secondary cells. This means that an electrical current must first be passed through the cell, transforming electrical energy into chemical energy. This operation is called

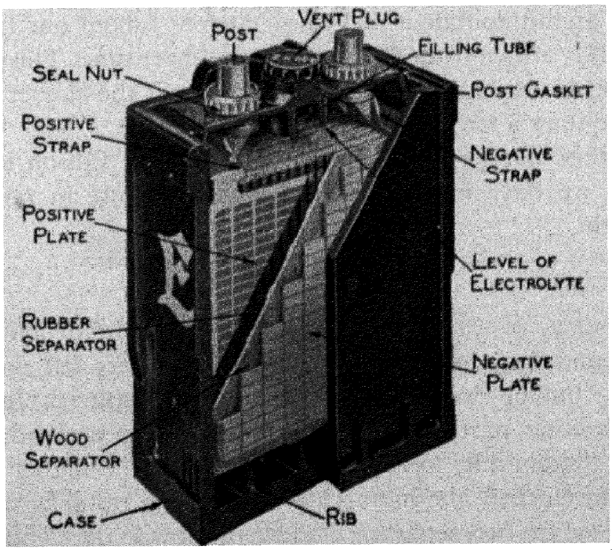

FIG. 204.—A storage cell. (*Courtesy The Electric Storage Battery Co.*)

charging. The cell will then have a potential difference and can act as a source of electrical energy. One type of storage cell

(Fig. 204) consists of lead plates separated by insulators of wood or porous rubber. The electrolyte is dilute sulphuric acid. In order to charge this cell, it is connected to a potential difference slightly greater than the potential difference of the charged cell. As the current flows through the cell, the electrical energy supplied is transformed into chemical energy. Alternate plates become coated with brown lead peroxide (PbO_2) and have a positive charge. The other plates form spongy lead and have a negative charge. There is usually one more negative than positive plate in the cell. For example, an 11 plate cell consists of 6 negative and 5 positive plates. Three such cells compose the ordinary 6 volt storage battery. The degree of charge is indicated by the specific gravity of the solution. A fully charged cell has a specific gravity of about 1.28. A properly discharged cell may fall to 1.180 without injury.

Storage batteries should have good care. Distilled water should be added when necessary, and the cell should not be allowed to stand in a discharged condition for a long time. In starting an automobile a very large current (about one hundred amperes) is drawn from the battery for a short time. This current heats the plates and may ruin the battery if the starter is used for more than a few seconds.

Another storage cell in common use is the Edison type. In this cell we have iron oxide and nickel hydrate in potassium hydroxide.

LIGHTNING

If a spray of water is blown into the air, the droplets form positive and negative ions. Most of the drops are left positively charged, having lost electrons to the atmosphere. As these colloidal water particles accumulate, they form a cloud with a positive charge. The freed electrons rise into the higher atmosphere and electrify the high-lying clouds. The result is a double cloud layer or two separate clouds, the lower part containing heavy positively charged droplets and the upper part negatively charged droplets (Fig. 205). Thus a rapid uprush of air is essential to the production of the electricity of a thunderstorm. Since a

thunder cloud is caused by a very rapid evaporation of water and a condensation of heavy drops in the cloud layer, the accompanying charge produces the lightning of the storm. Most lightning discharges are from one cloud to an adjacent cloud of opposite charge. If the upper cloud rises to a great height, the

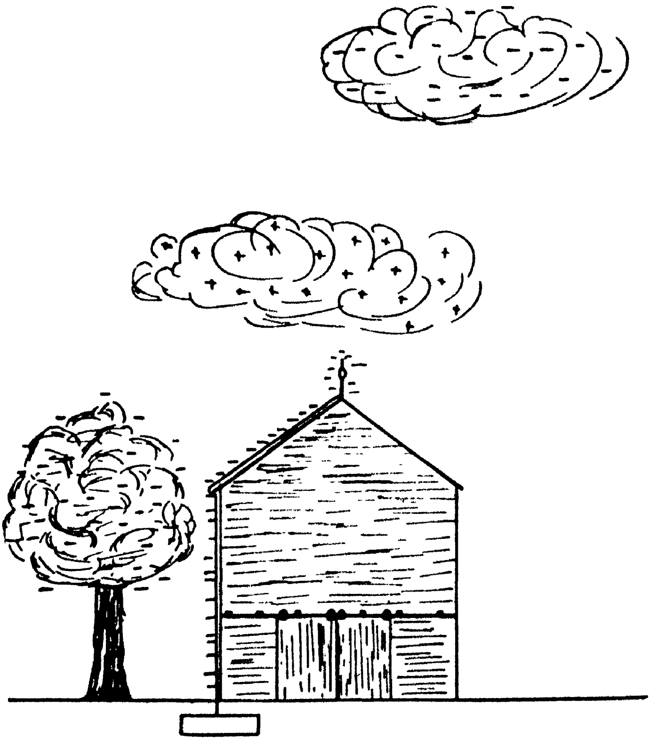

Fig. 205.—Conditions which produce a lightning discharge. The lower cloud is positive and the upper negative. The ground, tree and building have an induced negative charge. The discharge may take place either between the two clouds or between the cloud and building.

earth, which owing to "influence" has a charge opposite to the lower cloud, acts as the negative charge, the discharge taking place between the cloud and the earth.

In order that a discharge may pass, the air must contain ions. One of the most difficult problems in the study of lightning is to account for enough ions to pass a flash several miles long. To

produce these flashes, the potential difference between cloud and earth is of the order of millions of volts. A lightning discharge lasts for a time estimated to be from .002 seconds to 1 second. The current may be as great as 100,000 amperes (Fig. 206).

Many types of lightning are still in question. Ball lightning has not received a satisfactory explanation and indeed many

FIG. 206.—A lightning flash (*Bowden.*)

scientists doubt its existence. Sheet lightning is light reflected from distant clouds where lightning flashes are occurring.

The thunder which accompanies lightning has had many explanations, most of them ridiculous. The true explanation is that the noise is due to a compressional wave sent out by the rapidly heated air through which the discharge passes. The air

expands thereby causing an explosion. A good example is the explosion of a firecracker. When the powder in a firecracker burns, gases are formed which expand rapidly, blowing the paper container to bits. As a result a wave travels out through the air and upon striking the ear, gives us the noise.

Lightning rods have always been the subject of controversy. It is well established that they are of value only if they are carefully installed. A rod should be made of a good conductor and

Fig. 207.—A ten million volt lightning flash. (*Courtesy General Electric Co.*)

should have one end well connected to damp earth. Much of our modern information about the protective devices has been gained by the investigations of the General Electric Company, which has produced flashes in the laboratory at a potential difference of 10 million volts. Some of the discharges were 60 feet long (Fig. 207).

The lightning rod is valuable in that it has a pointed top. From this pointed top, the electrons from the earth and house leak into the air, thus reducing the charge and the potential

difference between the buildings and the cloud. In effect, we have a silent discharge flowing which prevents the destructive heavy current of the flash. Nevertheless, because our knowledge of lightning is still incomplete, the present form of lightning rod

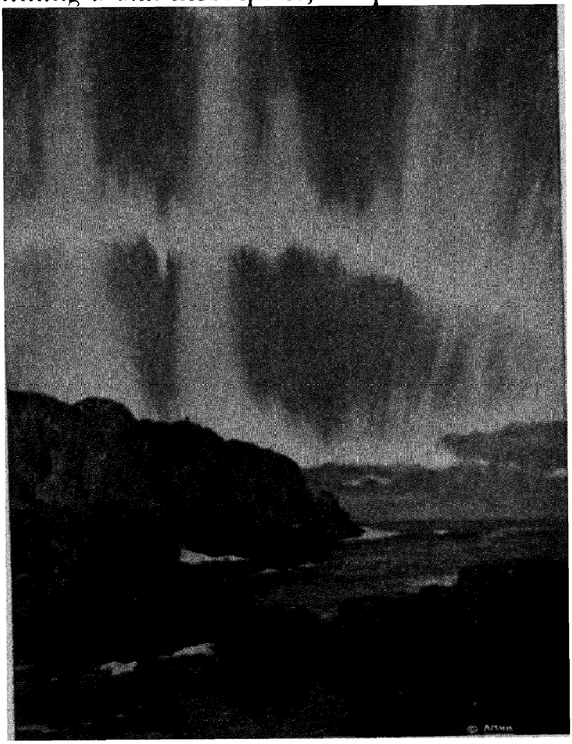

FIG. 208.—The aurora borealis of August 12, 1919, as seen at Ogunquit, Maine. (*From a painting by Howard Butler Russell, Courtesy of American Museum of Natural History.*)

does not always make a building secure. One difficulty is that lightning is usually an oscillatory discharge (see p. 341).

AURORA

Another type of atmospheric electrical discharge is the aurora, called in the northern hemisphere the "Northern Lights." This is a peculiar glow at the north and south magnetic poles, although the illumination is sometimes visible over a

great part of the earth. The aurora resembles a curtain of light waving in a breeze (Fig. 208). Many colors of the spectrum are present, although a greenish tint predominates. The spectrum is partly due to oxygen and nitrogen. One explanation is that the light is caused by ultra-violet rays shot out from the sun during a period of sun spots. These invisible rays ionize the air molecules and the ionized particles produce the aurora. Others believe that the electrons coming from the sun ionize the earth's atmosphere. McMillan relates that, as he traveled northward over the magnetic pole which is located in Baffin Land, the aurora was like a curtain of light through which he passed as he went forward.

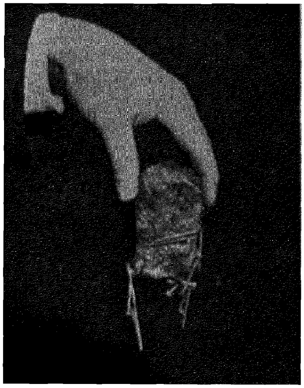

FIG. 209.—Loadstone.

MAGNETISM

Magnetism was known in very early times. It is related that a shepherd, named Magnus, in Asia Minor, accidentally found that a certain rock attracted his iron staff. The phenomenon is also mentioned in Chinese literature. Early peoples believed that certain magnetic mountains had the power of pulling the nails from the hull of a ship. Such a mountain is mentioned in the Arabian Nights. We now know this rock as magnetite or loadstone. It is an iron ore, an oxide ($FeO-Fe_2O_3$). The rock is weakly magnetic (Fig. 209).

It was later found that the metals, iron, nickel, cobalt, and some of their alloys had the property of acquiring magnetism and thus attracting other pieces of the magnetic metals. Modern research has shown that some alloys of these metals produce very strong magnets. Such materials are used for wrapping ocean cables, for the magnets of radio speakers, and for apparatus for talking movies. The modern French telephone was made possible by the alloy "*alnico.*"

It has long been known that the earth is a magnet (Fig. 210). It behaves as if a long bar magnet were inserted in the centro-

sphere. Because we believe the earth to be intensely hot at the center this simple explanation is not satisfactory, especially

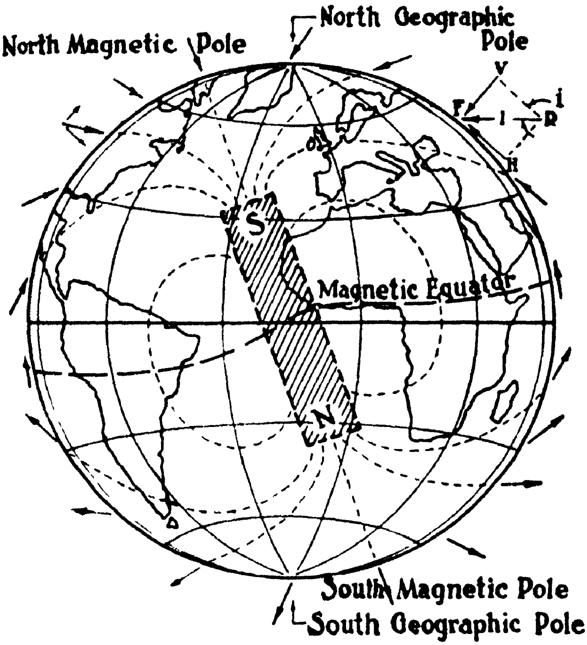

FIG 210 The earth's magnetic field. (*Foley.*)

since red hot iron is almost non-magnetic. Nevertheless, the earth's magnetism makes possible the magnetic compass which has guided man over the earth for centuries. A compass is a tiny magnet pivoted at the center. It points to the magnetic poles at the ends of the earth. Since the poles do not coincide with the geographic poles, a correction must be made by a mariner if he wishes to determine true north.

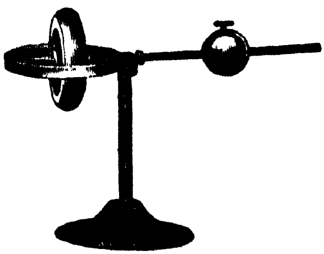

FIG 211 – The gyroscope. (*Courtesy Welch Mfg. Company.*)

In modern times, the magnetic compass has been replaced to some extent by the gyroscope (Fig. 211). This does not depend on the earth's magnetic property and can point to the geographic north pole.

ELECTROMAGNETISM

In 1819, a Danish scientist named Oersted, discovered, while lecturing to his class, that a wire carrying a current had magnetic properties. In Fig. 212 the magnetic needle is placed under the wire. When current flows in the wire, the needle deflects because of the magnetism produced by the current. This important discovery gave the first clue to the meaning of magnetism. We now believe that certain motions of electrons in the atoms produce magnetic properties. Since only iron, nickel, cobalt, and some alloys are strongly magnetic, it is probable that groups of

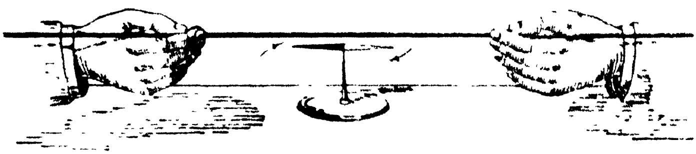

FIG. 212. - The Oersted experiment (*Bowden*)

atoms in these metals act as units giving the metals their property. Certain groupings are essential.

As an interesting demonstration, hold a long wire in a north-south direction, about one inch above a compass needle. As a current of about 10 amperes is passed through the wire the needle turns until it makes an angle with the wire. If the wire is now placed under the needle, the needle will reverse its direction.

Figures 213(a) and (b) represent graphically a bar of iron with these discrete groups of atoms. We note that the magnetic directions of the groups are not uniform. As we apply a magnetic force to these groups, the magnetic poles of the groups tend to become organized. There is, probably, no actual readjustment of the atoms. Such motions would break up the metal. There is a change in magnetic property, but not in structure. (Perhaps spinning electrons influence magnetic properties.)

After the discovery of Oersted, men wound coils of wire on iron bars (Fig. 214) producing the electromagnet, one of the most useful tools in electricity. They are used in telephone receivers, loud speakers, motors, generators, telegraph sounders, electric bells. The surgeon uses an electromagnet to extract particles of iron from the eye.

Although there is a great gap between the tiny horseshoe magnet and the powerful magnets of the steel mill, we now know

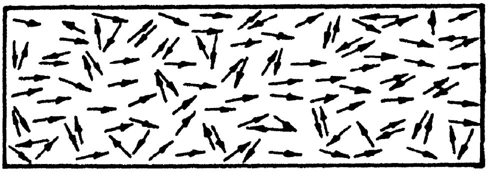

Fig. 213a.—A magnetic material in the unmagnetized condition.

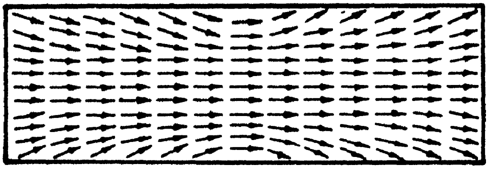

Fig. 213b.—The same bar in a magnetized condition. This sketch is based on theory and may not represent actual conditions in the metal. (*Foley.*)

that the essential cause of magnetism is the same in both; electrons moving within the atoms of the metal.

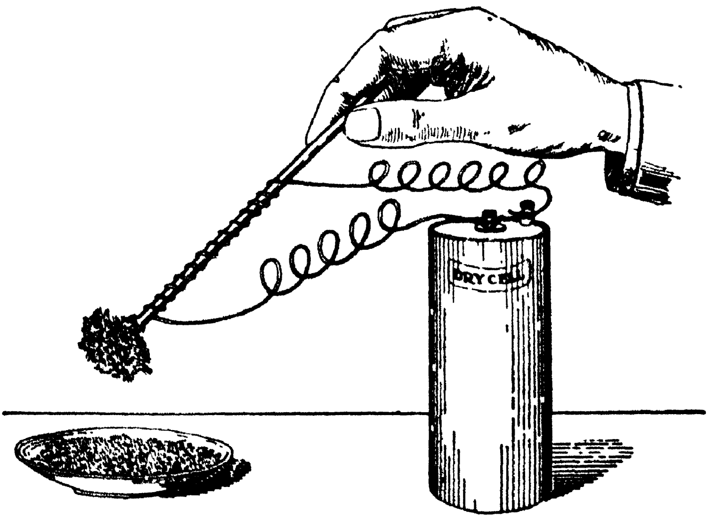

Fig. 214.—A simple electromagnet. (*Bowden.*)

On p. 12, it was noted that Hale discovered that sun spots acted like huge magnets. He assumed that this magnetic property

was due to the motion of an enormous number of electrons, whirling about in the spot.

ALTERNATING CURRENT

Up to this point we have described a current of electricity as though the electrons always moved in one direction. However, most of our current is of the alternating type. In this type of current, each pole of the generator is alternately positive and negative, so that the electrons oscillate back and forth. Because the transformer operates with alternating current, as will be shown in the next chapter, this type is used generally in our lighting systems. The current reverses many times each second and is described as a 25, 40, or a 60 cycle type. Much of the apparatus to be described in the following chapter is of the alternating current type.

THERMIONS

Richardson, while a lecturer at Cambridge University, discovered that a wire heated to a high temperature has the property of boiling off electrons into the surrounding space. This means that each tungsten lamp bulb is filled with electrons which have left the filament as free electrons. He called these electrons "thermions". This startling discovery made possible the modern radio tube or audion as will be explained in the following chapter.

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VISUAL AID

ZEUS (A film on lightning)—General Electric Co.

TOPICS

Boxing a Compass.	The Atlantic Cable.	Permalloy.
Aurora Borealis.	Ball Lightning.	The Gyrostatic Compass.

PROBLEMS

1. What is the cause of the earth's magnetism?
2. How could you prove the earth to be a magnet?
3. What is the difference between static and current electricity?
4. Why do gasoline trucks always drag a chain?
5. Explain the operation of a lightning rod.
6. Explain the difference between the action of a storage battery and a dry cell.
7. A lamp is marked 25 watts, 120 volts. Explain what is meant.
8. A 6 volt storage battery is connected to a 30 ohm lamp. What current will flow?
9. What is the meaning of the term ampere?
10. What is an insulator? A conductor?
11. Why not light the house with the automobile battery?
12. What is a watt? A kilowatt-hour?
13. What causes thunder?
14. What is the cause of lightning?
15. What is the cause of the aurora?
16. For how many hours can we operate a toaster for the cost of 20 cents? (In the calculation use the rate in your locality.)
17. Calculate the cost of operating a flat iron for 10 hours if the rate is 10 cents per Kilowatt hour.
18. If the 120 volt socket is "shorted" by a wire of $^{1}/_{10}$ ohm resistance, what will be the current?
19. Where is the safest location when lightning discharges are occurring?

EXPERIMENTS

1. Connect a dry cell, a rheostat (resistance), a key, and an ammeter in series. Read the ammeter. Vary the rheostat and note the effect on the ammeter reading. Does your result agree with Ohm's Law?

2. Connect a dry cell to a voltmeter. Read the potential difference.

3. Connect a cell, an ammeter, a key, and a rheostat in series, and connect the voltmeter *directly* to the cell. Record the potential difference, and the current for three values of the resistance. From the readings calculate the values of the resistances by means of Ohm's Law. (Fig. 215.)

4. Connect a cell, a key, an ammeter, and two resistances in series. Adjust the rheostats to one of the positions used in 3, and note the effect on the current.

5. Using a lamp bank connected to the lighting circuit, connect an ammeter and a voltmeter to the circuit Read the potential difference and the current through the lamp. Compute the resistance of the lamp. Repeat with two lamps in parallel. Use a toaster or iron. Calculate the watts for both the lamps and toaster.

6 Cut a dry cell in half and examine its structure.

7. Examine the plates of a discarded storage cell.

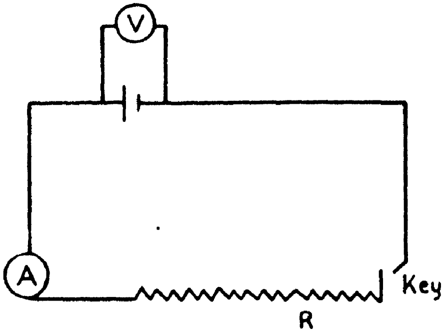

FIG 215

8 Cover a bar magnet with a sheet of paper and dust iron filings over the paper. The arrangement of the filings illustrates a magnetic field.

Repeat the experiment with a horseshoe magnet

(If blue print paper is available make a permanent record of the filings.)

Note. Have the instructor check each wiring arrangement before you press the key. This precaution will prevent damage to the meters in case there is a short circuit.

20

APPLIED ELECTRICITY

"Electricity, carrier of light and power, devourer of time and space, bearer of human speech over land and sea, greatest servant of man."

Eliot

IN THE previous chapter, various fundamental principles of electricity were interpreted and a few pieces of electrical apparatus were described. We shall now describe some of the

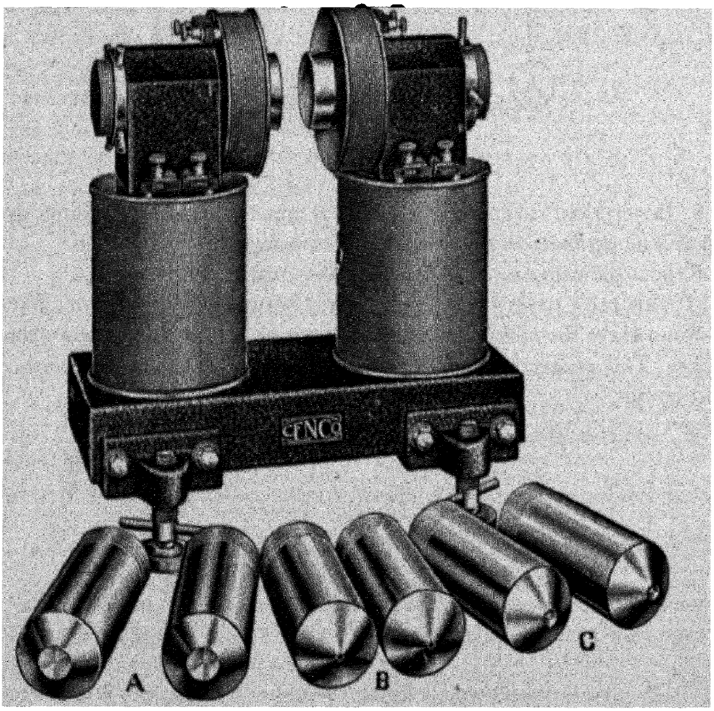

FIG. 216.—A commercial electromagnet. (*Courtesy Central Scientific Company.*)

more modern methods for the production of electricity. Because a complete explanation of modern motors and generators requires an excellent background in electrical engineering, it will be necessary to describe such machinery very briefly. There

are many excellent texts to which the interested reader can turn for more detailed explanations.

Historically, modern electricity may be said to have begun with the discovery by Oersted, that a wire that is carrying a current acts like a magnet (see p. 321). Electrons in motion produce magnetic fields. Oersted held a wire, through which a current was flowing, over a compass needle, and found that the wire had the properties of a magnet. The magnetic effect became stronger as the current was increased. If we bend the wire into a circle, the magnetic field at the center of the circle will be strong. To further increase the strength of the field at the center, we may wind a coil of many turns. With such a coil, a small current will produce a strong magnetic field. We may state this more accurately by saying, that *the field strength depends upon the number of turns and the number of amperes flowing in the coil.* If the turns are distributed in the form of a spiral or helix, we have a coil having poles like a bar magnet. If, in addition, we place inside the helix a bar of soft iron, the magnet is very strong and is much more effective than a bar magnet (Fig. 216). The great advantage of such a magnet is that the magnetic property disappears when the current is turned off, since soft iron does not retain the magnetism after the current has stopped. Some of the common uses for electromagnets are in the doorbell, in the telegraph sounder, in lifting magnets, in surgical magnets, in automobile horns, in motors, in generators, and in transformers.

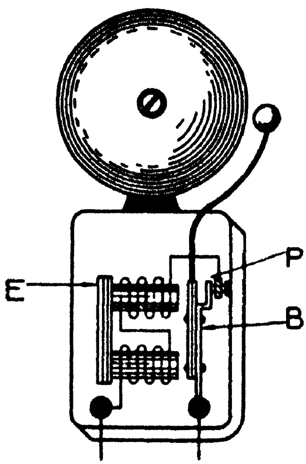

FIG. 217.—The electric bell.

The door bell has an electromagnet bent in the form of a U (Fig. 217). A bar of soft iron *B* is hinged above the magnet, being held in place by a spring. When the push button on the door is pressed, the circuit is completed and the magnet *E* attracts the bar *B*. As the bar moves toward the magnet, it strikes the bell and at the same time the circuit is broken at *P*.

The bar now flies back, closes the circuit, and is again pulled toward the magnet. The process continues as long as the push button is held.

In 1831, Faraday (Fig. 218) made a very important discovery which made possible all of our present electrical age. Inasmuch as Oersted had found that an electrical current (electrons in motion) could produce a magnetic field, Faraday reasoned that

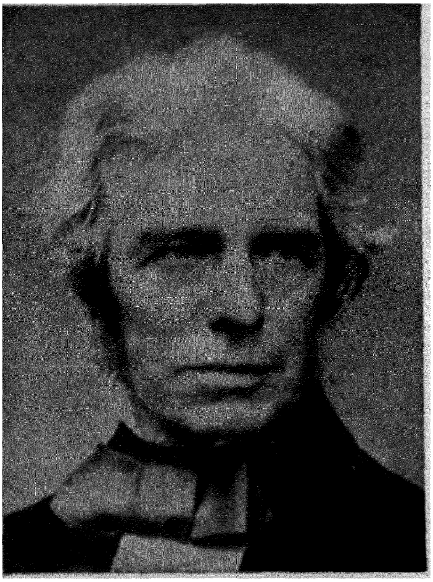

FIG. 218. Michael Faraday (1791–1867). One of the greatest of scientists. Discovered the laws of electrolysis, of induced currents and of the relations of magnetism and light. (*Hackh.*)

in some way magnetism ought to produce electricity. In the course of his experimentation, he found that when a wire was moved back and forth between the poles of a horseshoe magnet, a current flowed in the wire as long as the wire was moving. (Fig. 219.) While the wire was being pushed in, current flowed in one direction. When the wire was being pulled out, a current flowed in the reverse direction. He also noted that there was no current in the wire when there was no motion. In order to observe the current, he connected the wire to a current-measur-

ing instrument called a *galvanometer*. In the drawing, it will be noticed that, with the north pole of the magnet underneath the wire, a motion of the wire inward causes a current to flow toward

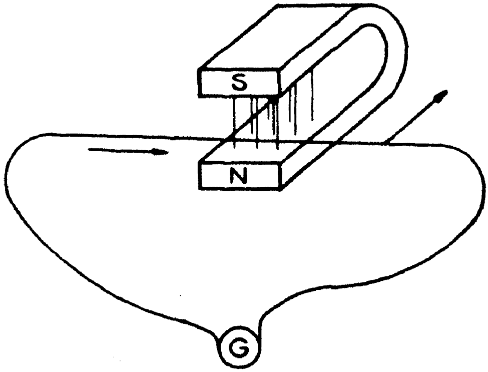

FIG. 219.

the right. When the wire is pulled out, the current flows to the left. If a coil of wire and a bar magnet are used as shown in Fig. 220, the same effects are observed. When the magnet is

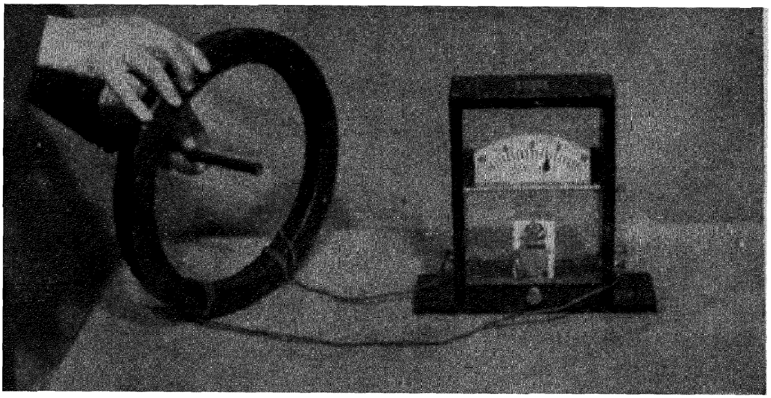

FIG. 220.—**A current induced by means of a bar magnet. Motion of the bar magnet to and fro induced an alternating current in the coil.**

thrust into the coil, the galvanometer needle moves in one direction. If the magnet is pulled out, the needle reverses its direction. The motion of the magnet in and out causes a current to flow

in two directions, thus constituting a cycle. As we have stated in the preceding Chapter, this is called an alternating current.

If an electromagnet is used instead of the bar magnet, we get the same result. Moreover, a varying current in the electromagnet is just as effective as a moving magnet. The transformer utilizes this principle. (Fig. 221.)

A valuable method for the study of induction is to perform the experiments described below in the following order:

Initially, thrust a straight wire, which is connected to a galvanometer, between the poles of a horseshoe magnet.

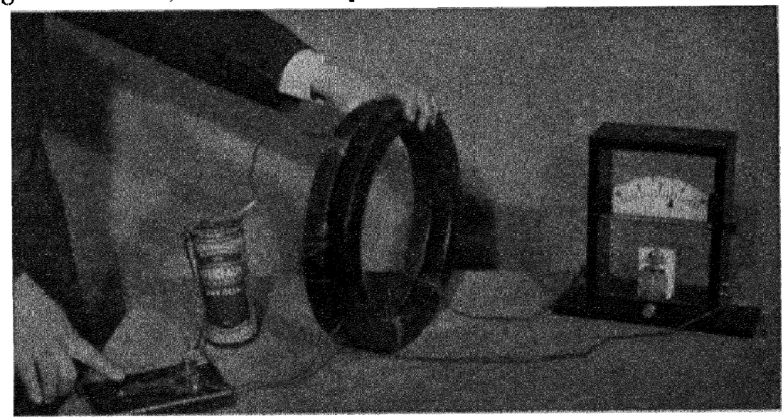

FIG. 221.—Induced currents. The secondary coil is connected to the galvanometer. The primary coil is connected in series with a dry cell and a key. At the instant the key is pressed and released, a momentary current flows in the galvanometer.

Next, coil the long wire into the form of a helix and thrust a bar magnet into the coil.

Replace the bar magnet by an electromagnet. Open and close the circuit in the electromagnet.

It is hard for us to realize in these modern days that commercial electricity was unknown until about 1880. Before this time only chemical batteries were available. Experimentation in electricity was slow for many years, until stimulated by the demand for electrical lighting. Although Faraday in England and Henry in the United States discovered the fundamental principle of the generator, other inventors made the machine

practicable. In the year 1860, only copper bars were available, copper wire being unknown. The copper bars were wound with strips of cotton cloth for insulation. The first generator made in the United States was constructed of these hand-insulated bars.

THE TRANSFORMER

In this machine (Fig. 222), two entirely separate coils of wire, one called the primary and the other a secondary, are wound on a common iron core. As the alternating current flows in the primary, an alternating current of the same frequency (cycles per second) is produced (induced) in the secondary. It is not

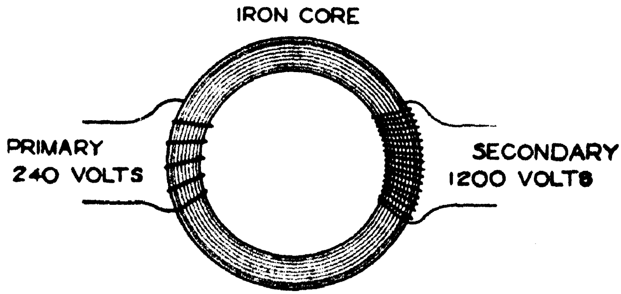

FIG. 222.—Sketch of a transformer.

necessary that the current in the primary be alternating as long as it is varying.

Since the transformer is a machine, we shall discuss it in terms of power. For an efficiency of 100%, the watts output at the secondary would equal the watts input at the primary, or in other words, the volts times the amperes in the primary would equal the volts times the amperes in the secondary. It will be noted that in Figure 222 the number of turns of wire on the secondary is 5 times the number of turns on the primary. This means that 240 volts on the primary produce 1200 volts on the secondary.

$$\frac{\text{Turns primary}}{\text{Turns secondary}} = \frac{\text{Volts primary}}{\text{Volts secondary}}$$

If the transformer is a 12,000 watt machine, the maximum safe current in the primary will be 12,000/240 or 50 amperes. In the secondary, the maximum safe current would be 12,000/1200 or 10 amperes. Such a transformer is said to be of the step-up type. (Actually the efficiency is about 98%, so that the watts output will be somewhat less than the watts input.) Because of the fact that a transformer is a machine that has no moving parts, it is one of the most efficient of all electrical devices.

There are many applications of the transformer principle. The power company often wishes to step up the voltage so as to transmit power economically over long distances. Large transformers (Fig. 223) designed for this purpose are familiar sights at power stations and along electric railways. In the high tension wires, which are supported on tall towers, the potential difference may be as high as 250,000 volts. The higher the voltage for a given power distribution, the smaller the current. In consequence, the heat loss is less and greater economy results. The upper limit to the usable voltage is set by the insulators and the supports. With very high voltage, a corona discharge takes place through the air, thereby causing a loss of power.*

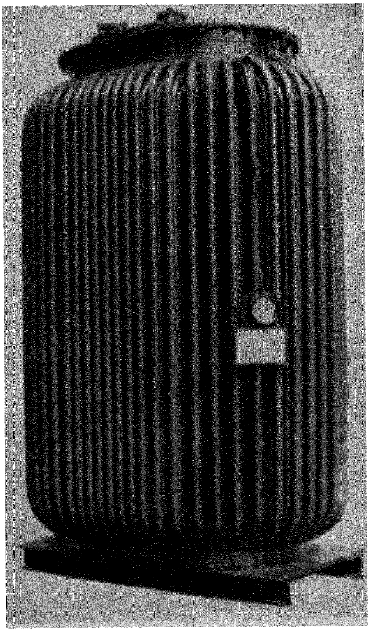

Fig. 22[illegible] [illegible] (Co[illegible])

One very important use for the transformer is in house lighting. The potential difference between the wires on the street poles is several thousand volts. Since this voltage would be dangerous in the house, a transformer is hung on the pole nearby

* Corona discharge causes the blue glow seen at night around high tension lines.

(Fig. 224) and the potential difference is decreased (stepped down) to 110 volts or in some cases to 220 volts. Toy transformers transform 110 volts to 6 volts.

Transformers are also used in radio sets. Here they are employed to increase the voltage or the current. The frequency of the alternating current determines the type of transformer used. If the number of cycles is great, for example, one million

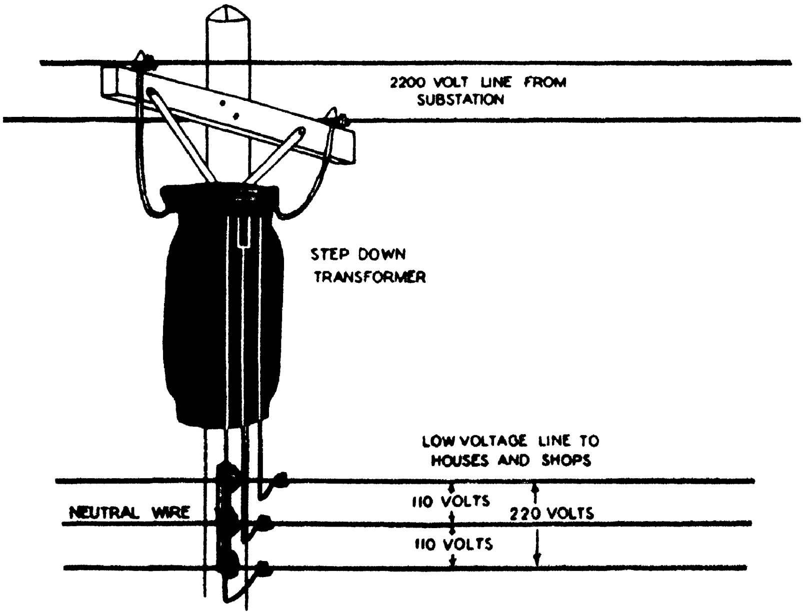

FIG. 224 — A step-down transformer. (*Hal.*)

(radio), the transformer usually has no iron core. On the other hand, for a few thousand cycles, iron core transformers (audio) are used.

Many persons are puzzled by the fact that, although the primary of a door bell transformer is connected to the line at all times, no current flows until the button is pushed. As long as the secondary is an open circuit, the transformer [illegible]gh resistance (impedance) for alternating current, so that very little current flows in the primary coil. However, because the

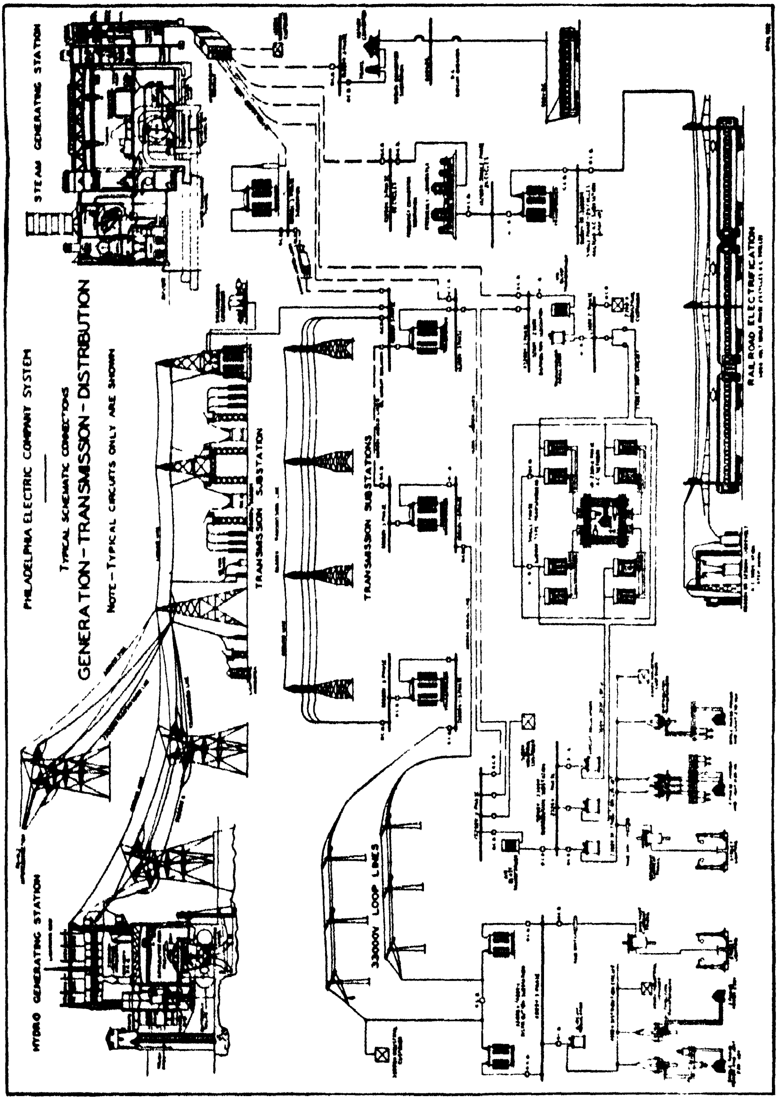

FIG. 225.—Philadelphia Electric Company System. (*Courtesy Philadelphia Electric Co.*)

efficiency is not 100%, a small current is continually heating the transformer.

The Philadelphia Electric Company, which supplies energy to much of eastern Pennsylvania, generates a part of its power at the Conowingo hydroelectric plant. The power is generated at approximately 13,200 volts, and is stepped up by great transformers to 220,000 volts for the long distance transmission lines. The power is transmitted at this voltage over high tension lines to Plymouth Meeting. At this point there are 220,000 volt connections between the Philadelphia Electric Company, and the systems of the Pennsylvania Power and Light Company and the Public Service Electric and Gas Company of New Jersey. Part of the power is stepped down to 66,000 volts for distribution to Philadelphia and the surrounding territory. At Philadelphia, the voltage is again stepped down to 13,200 for substation supply and also to 2300 for the street lines. Similarly, in the suburban territory the voltage is stepped down to 33,000 for substation supply and also to 4000 for the street lines. At the house there is a further step-down to 115 volts for safe house use (Fig. 225). Because of the heat loss there is a 6% loss of energy in the long distribution from Conowingo to Plymouth Meeting. Were it not for the high voltage, there would be a much greater loss. On p. 308, it was stated that the heating effect of the electrical current is I^2Rt, where I is the current, R the resistance, and t the time in seconds. It is evident that economical transportation of electrical power requires that the current be as small as possible. Hence the need for high voltage.

GENERATORS

To produce an alternating current, a machine called a generator or alternator is used. This is a device for converting mechanical energy into electrical energy. Its principle is a direct application of the discovery of Faraday that the motion of a wire in a magnetic field produces electrical energy at the expense of mechanical energy. The work done in moving the wire causes the electrons to flow in the wire. A simple generator might be made by moving a wire back and forth, but a more desirable

arrangement is to rotate a coil of wire between the poles of a magnet (Fig. 226). The coil (armature) is turned either by water power or by a steam or gas engine. Inasmuch as only relative motion is needed, the larger generators are designed in such a way that the electromagnet (rotor) rotates, and the coils (stator) are at rest (Fig. 227). The most common frequency is 60 cycles per second, although 25 and 40 cycles are sometimes used.

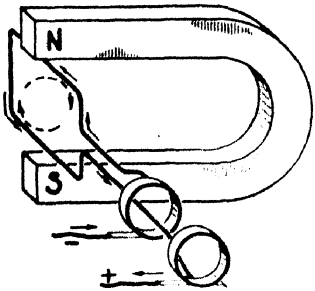

FIG. 226.—Essentials of an A C generator. ([illegible])

By a slight change in design, the generator produces direct current. The current output of a direct current machine flows in only one direction in the circuit. To accomplish this, a split ring replaces the two rings of the alternator (Fig. 228).

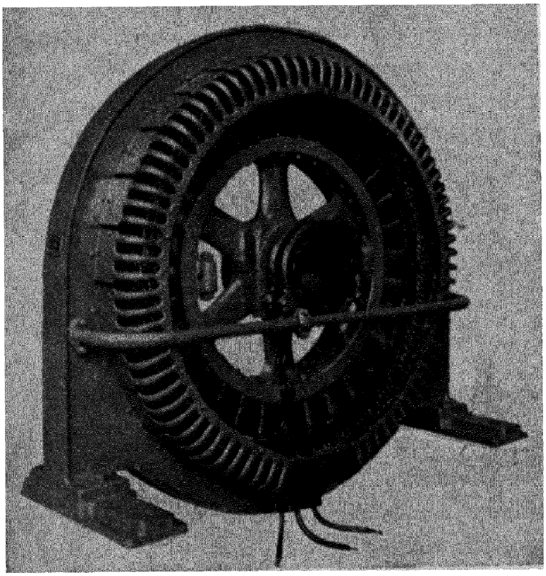

FIG. 227.—An alternating current generator. (*Courtesy General Electric Company.*)

An interesting application of the generator principle is the ribbon microphone. In this device, the energy of the sound from

the voice causes a ribbon of metal to move to and fro between the poles of a magnet. This motion produces a tiny current which is amplified by radio tubes.

To explain the action of a generator, it is necessary to introduce the idea of lines of magnetic force. We think of the space between the poles of a horseshoe magnet as being filled with a magnetic property, which we call lines of force. When the wire is thrust in, the force lines act like rubber bands, and work is necessary to thrust them aside. This work results in electron motion in the wire. The voltage produced in the wire depends upon the speed with which we cut these lines of magnetic force.

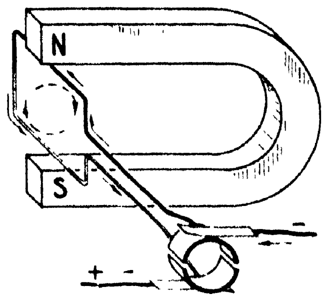

FIG. 228. Essentials of a D.C. generator (*Foley.*)

THE ELECTRIC MOTOR

To understand the principle underlying the motor, we must again recall the discovery of Oersted that a wire carrying a cur-

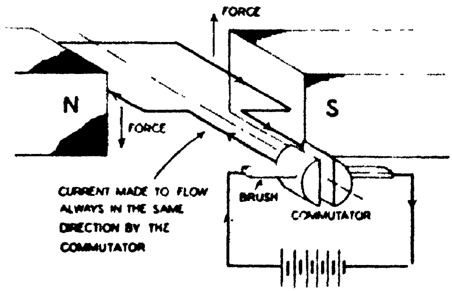

FIG. 229.—A direct current motor. (*Heil.*)

rent acts like a magnet. If we place between the poles of a horseshoe magnet a wire carrying a current of electricity, we will have two magnets acting on each other. As a consequence, the wire will be moved in the field. The combination of a magnet and a wire carrying a current constitutes a motor. In Figure 219, if the north pole of the magnet is underneath the wire, and if a current is flowing toward the right, the wire will be pushed forward.

Instead of a straight wire we usually use a coil rotating between the poles of a magnet. In Figure 229 we see that the side of the coil moving down has a current moving into the page. The side moving up has a current moving out from the page. This causes a rotation and, by the addition of a commutator (split ring), the current can be caused to flow in such a direction that the rotation of the coil is continuous. The moving coil is called the armature and the magnet is called the field.

HEATING APPARATUS

A very important application of electricity is its use in heating devices. These pieces of apparatus contain some materials of high resistance: the flat iron and toaster use a ribbon of the alloy chromel; the electric range often uses a mixture of iron and carborundum. Electric heating devices are rather expensive to operate and at ordinary house rates usually cost more than other heating methods.

THE TELEPHONE (Far-off Sound)

In 1876, Graham Bell invented a device by which he was able to transmit his voice to an adjoining room. The first historic words were "I want you, Watson." This first telephone was very crude (Fig. 230) and was improved by Edison who devised the modern carbon grain transmitter (Fig. 231).

The telephone transmitter consists of a loose mass of granulated carbon between two carbon blocks C, one fixed and other movable and fastened to the iron diaphragm D_1. As the sound energy of the voice enters the microphone M, the diaphragm moves back and forth. This motion varies the pressure on the carbon grains. As a result, the resistance of the carbon changes, becoming lower as the pressure increases, thus producing a varying current in the line. The varying current actuates the electromagnet in the receiver or earpiece R. The receiver is a horseshoe magnet with an electromagnet wound on the poles. In front of the poles is an iron diaphragm D_2. The varying current causes a varying magnetic field in the electromagnet and this field pulls the iron plate back and forth, thereby reproducing

the original sound. All carbon microphones and some magnetic speakers are of this type. Figure 232 shows the construction of the modern hand telephone.

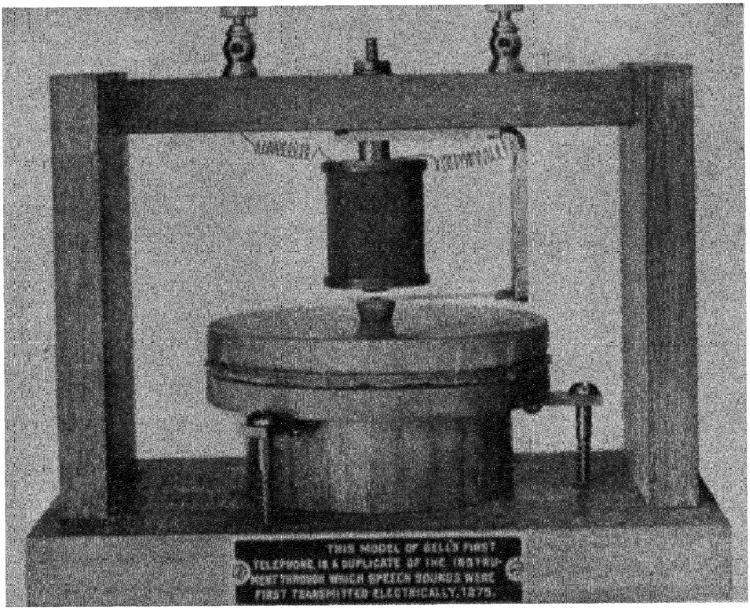

FIG. 230.—Model of the original telephone. (*Courtesy Bell Telephone Co.*)

Magnetic loud speakers are limited in their output of energy. When the amount of energy delivered is too great, the quality of the tone becomes unsatisfactory. A modern type of speaker is the dynamic type. In this speaker (Fig. 233), there is an

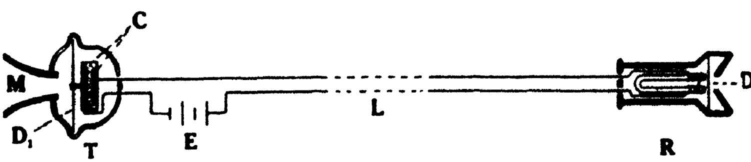

FIG. 231.—The telephone circuit. (*Foley.*)

electromagnet NS. Around this magnet is wound a coil of wire C. As the varying current D flows in the coil, the coil moves back and forth and an attached paper cone is set into

vibration. This type was until recently used in most modern radio receivers, but very recently a new alloy, "Alnico," has been produced, which has such a strong magnetic field that it is

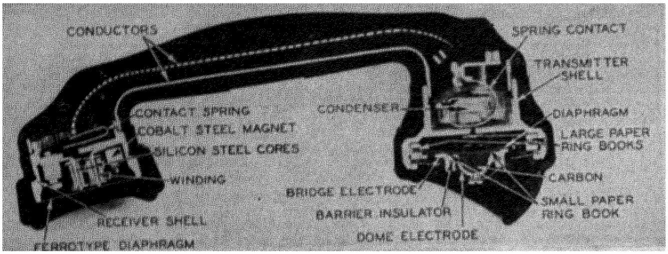

Fig. [illegible] The hand telephone [illegible] Co.)

replacing the electromagnet. The dynamic speaker is really a small motor.

ELECTRICAL RADIATIONS AND RADIO

One of the most amazing results of scientific research is the frequency with which some laboratory experiment becomes of great scientific importance and commercial value. Radio may be said to have been borne in the brain of Clerk Maxwell (Fig. 234). Maxwell was a mathematical physicist who, in the course of his studies, became convinced that light was a form of electromagnetic radiation. He reasoned that, if this were true, there ought to be a type of invisible electrical radiation which could be sent from place to place in the same way that light travels. During the course of his calculations he devised a model of the ether in which these waves of electrical energy could travel.

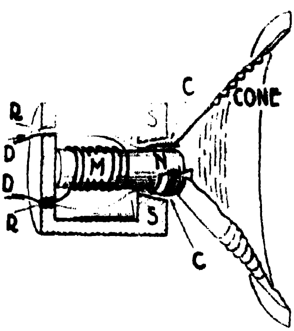

Fig. 233. Dynamic speaker. (*Foley.*)

In 1888, Heinrich Hertz first produced these radiations in the laboratory and was able to send them from one room to

another. He constructed the first wireless transmitter and receiver.

Before describing the experiments of Hertz, we shall explain the meaning of the term *oscillation*. In order to do this, we shall use the pendulum as an illustration. If we suspend a ball from a

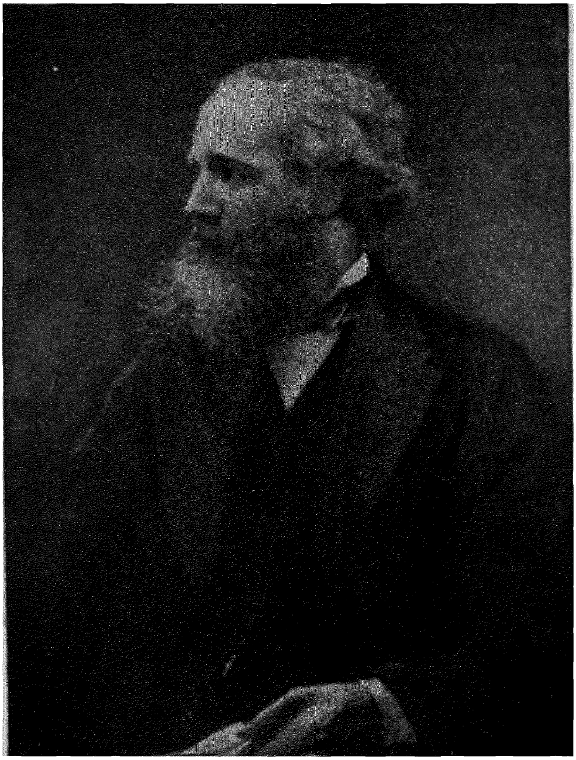

FIG. 234.—James Clerk Maxwell (1831–1879). A famous physicist and mathematician; one of the originators of [illegible] waves. (*From Millikan, Gale, and Edwards, "A Fir*[illegible] *and Co.*)

cord and start it moving to and fro, we shall find that the amplitude (size of swing) of the vibration slowly decreases as the ball swings and that after a time the ball will come to rest. This type of motion is called a *damped oscillation*. The pendulum has lost its energy as it moved to and fro. On the other hand, in the clock pendulum, all oscillations are maintained by the spring or

weights and are called *undamped oscillations*, since the swings have the same amplitude. The number of vibrations per second is the frequency. Radio frequencies are expressed in kilocycles (thousands of cycles) or megacycles (millions of cycles). In the pendulum, the energy alternates between the potential and kinetic forms as the pendulum swings.

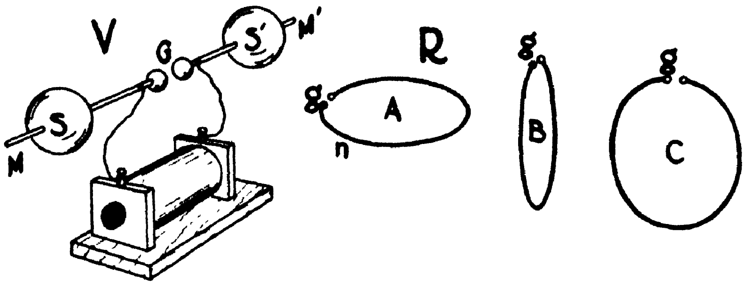

FIG. 235.—The type of apparatus used by Hertz. V represents the transmitter R is the receiver. (*Foley*.)

Let us suppose that we have two balls S and S^1 connected to rods (Fig. 235), so that a small gap exists between the rods. If we connect A and B to a source of high potential, one ball will acquire a negative charge and the other a positive charge. When the charge becomes too great, a spark will jump the gap and the balls will lose the charge. However, a rotating mirror will show that the balls charge up again but in the opposite direction, and this charging and discharging will continue for a small

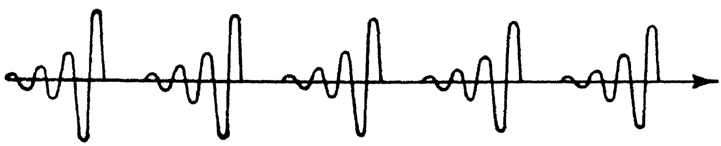

FIG 236.—Damped oscillations. (*Foley*.)

fraction of a second, until the energy stored in the balls is used up as heat, or is radiated out into space as electric waves. The high voltage source again charges the balls and the process is repeated. These rapid reversals of charge produce damped oscillations (Fig. 236). We find that all electrical sparks, including lightning discharges, are oscillatory, the frequency usually

being very high. The energy is alternating between the electrical (potential) and the magnetic (kinetic) forms.

Hertz used two plates between which there was a spark gap (Fig. 235). His plates were charged by an induction coil. At the other side of the room he used a loop of wire having a small adjustable gap. He found that sparks jumped the gap of his loop whenever there was sparking between the balls of the sending system. Each time a spark jumped the gap, oscillations were set up between the plates and, as a result, electrical waves

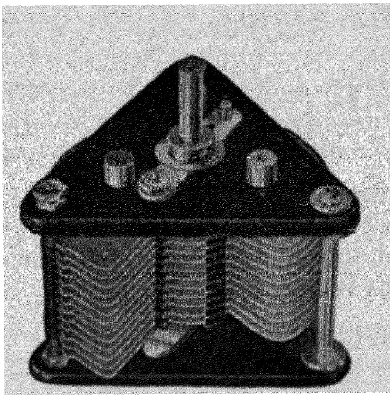

FIG. 237.—Condenser of variable capacity. (*Weld and Palmer.*)

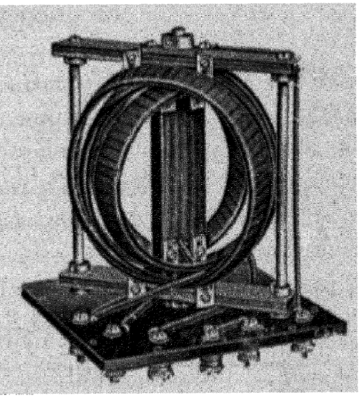

FIG. 238. ... inductance. (*Weld and Palmer.*)

passed out from the apparatus. He found that the waves could be reflected and refracted; they had similar properties to light waves. Actually, the system consisted of a *condenser*, a *spark* gap, and an *inductance*. If the condenser and the inductance are large enough, we find that the spark has a musical note indicating that the frequency is in the audible range. By adjusting the inductance or capacitance we can change the pitch of the note.

Marconi made possible long distance transmission and reception of electric waves. He used an aerial for one plate. A plate embedded in the ground was a substitute for the other plate of the Hertzian apparatus. By means of his apparatus he was able, in 1910, to send signals from England to Newfoundland. Such damped oscillations were rather difficult to maintain. With the invention of the vacuum tu... ies of

undamped waves could be sent out from a transmitter. Two outstanding scientists in this field are Fleming and DeForest. To these men we owe the invention of the modern radio tube (audion).

Actually, there are three essential parts of every modern electrical oscillator: a condenser C (Fig. 237) an inductance L (Fig. 238), and a vacuum tube. The frequency of the oscillations is determined by the equation

$$\text{Frequency} = \frac{1}{2\pi\sqrt{LC}}$$

If, for example, the inductance L is one tenth millihenry (.0001) and the capacitance C is 500 micro-micro-farads (500×10^{-12}), the frequency emitted will be about 730,000 cycles or 730 kilocycles. To reduce this to wave length, divide the velocity of electric waves (3×10^8 meters per second) by the frequency (73×10^4 vibrations per second). The result is 410 meters. Such a wave is in the broadcast band.

TABLE OF ELECTRICAL RADIATIONS

Station	*Wave Length Meters*	*Frequency (Cycles per Sec.)*
Dresden	233	1,285,000
Radio Paris	1,643	182,000
Moscow	1,745	172,000
W.J.Z. New York	395.5	760,000
W.G.Y. Schenectady	379.5	790,000
K.F.I. Los Angeles	486.5	640,000
W.C.A.U. Philadelphia	256	1,170,000
G.S.J. England	13.93	21,530,000
D.J.L. Germany	19.85	15,110,000
12 R.O. Rome	31.14	9,635,000

THE RADIO TUBE

The modern triode (three element tube) consists of a filament which emits electrons, a plate which collects them, and a grid which regulates the electron flow. In Fig. 239, F represents the

filament, G the grid, and P the plate. The A battery lights the filament, and the B battery makes the plate current possible (Fig. 240). In the previous chapter mention was made of the discovery of thermions (electrons evaporated from a white hot metal as water molecules evaporate when water is heated). It has also been discovered that the emission of electrons is much more copious when the metal is coated with such materials as lime and barium carbonate. The coating makes possible an emission of electrons even with the wire at dull red heat.

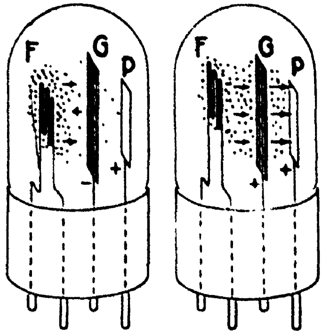

FIG. 239. Sketch of a radio tube. (*Foley*.)

The plate is a piece of nickel that surrounds the filament. This electrode is kept at a constant potential by the "B" battery, and the electrons move toward it as they evaporate. In Fig. 239, a current flows in the circuit as a result of the electrons moving across from the filament F to the plate P.

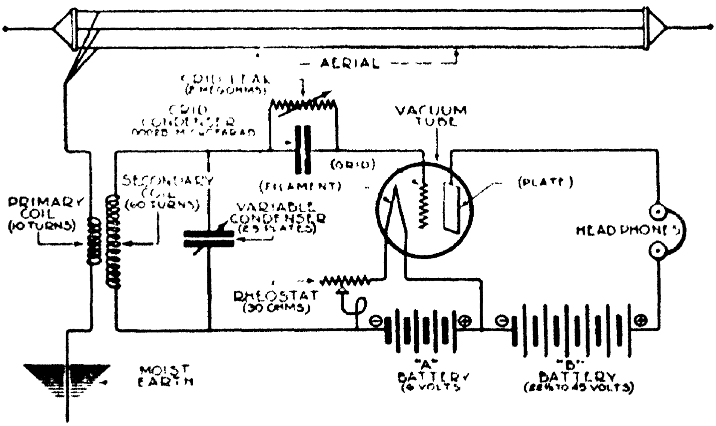

FIG. 240.—Sketch of a one tube receiving set. (*Bowden*.)

A wire mesh G, called the grid, is placed between the filament and the plate to influence the flow of electrons. If it is at a positive potential, it will tend to increase the electron flow. When it is sufficiently negative with respect to the filament, it may stop the

current entirely. The electric waves from the broadcasting station produce a rapidly alternating electron flow in the antenna of the receiver. (Figure 240 illustrates a simple one-tube receiving set.) If the flow is in such a direction that the grid is positive, the electron current in the tube will increase (Fig. 239). If the grid is negative, the current will decrease. This action produces a varying direct current in the telephone receiver or loud speaker. Moreover, the slight variation in the grid potential produces a large variation in the plate current, so that the tube is said to amplify as well as detect the incoming radio current. By using several tubes in succession, the current can be made great enough to operate a loud speaker. The grid may be compared to a gate which controls the flow of electrons from the filament to the plate. It is the heart of the receiving tube.

The modern tetrodes, pentodes, and hexodes contain more than one grid. These grids called screen, suppressor, and control, have certain effects which make the tubes much more sensitive than the simple triode tube. Whereas, the triode, 201A, tube had an amplification factor of about 5, the screen grid tube, 224A, has an amplification factor of nearly 2000. This is one of the reasons why the modern receiver has a very high sensitivity although the number of tubes is less than in the receivers of a decade ago. The interested reader should consult the R.C.A. tube manual for further information about the new tubes of high sensitivity.

With the advent of radio, people wished to be able to operate the set from the alternating current of the house. For several years this was not possible, because the alternating current produced a loud hum in the receiver which made clear reception impossible. The reversals of the current in the filament changed its temperature rapidly, causing a variation in the filament-plate current. Since it was early realized that the only function of the filament was to emit the electrons, it was found possible to place the filament in a coated nickel sleeve. The filament, operated by alternating current, heated the sleeve, which in turn became a steady emitter of electrons. Because of the necessity for heating sleeve, a radio set does not go into operation until several

seconds after the current is turned on in the filament. Devices were also perfected to produce a steady plate voltage from the alternating current. This was done by rectifiers which changed the alternating current into direct current and by filters which produced a steady current similar to that of a storage battery. From this time forward, the receiver could be operated from the alternating current circuit.

Within the last 5 years, there has been a remarkable improvement in radio receivers. A great number of new tubes, with excellent reception properties, has brought the world to our door. One need only contrast the receiver of 1938 with the receiver of 1924 to realize the great improvement in reception. We find fewer tubes, better quality of tone and simplified tuning. Instead of a battery of dials we have only one, or we may even use push buttons. A small child can operate the modern receiver. The latest improvement is the metal tube. This has simplified the receiver by eliminating certain parts so that the set is lighter and more compact.

In the early days of radio, it was believed that electric waves of short length (50 meters and below) were useless. Consequently, this band was turned over to the amateurs for experimental purposes. Later, it was discovered that such waves could travel great distances without much loss of intensity. Today, the entire world is in communication by means of short waves. Reception from a station several thousand miles distant is a nightly occurrence. Short waves are less susceptible to local electrical influences, such as static electricity.

In order to account for the great distances which radio waves travel, scientists believe that there exists a layer of ions (Heaviside layer) in the upper atmosphere which acts somewhat as a mirror in that it reflects the waves so that they are able to follow the curvature of the earth. The layer rises at night, permitting long distance reception. The cause of the ionized layer is unknown.

A complete discussion of the modern receiver is outside the scope of this text. Some of the references give excellent descriptions of modern receivers.

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Meister. MAGNETISM AND ELECTRICITY. Scribners.
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Foley. COLLEGE PHYSICS. P. Blakiston's Son & Co., Inc.

PROBLEMS

1. Describe a telephone receiver.
2. What is the purpose of the grid in an audion?
3. What is a damped oscillation?
4. Why do power companies use high tension wires to transmit power over long distances?
5. What is the purpose of the filament in a radio tube?
6. Why is a radio tube often called a valve?
7. A radio station is broadcasting on a frequency of 550 kilocycles. What is the wave length? Answer. 545 meters.
8. A short wave station in England broadcasts on a frequency of 9.5 megacycles. What is the wave length? Answer. 31 6 meters.
9. Describe two types of loud speakers.
10. What is the difference between a motor and a generator?
11. Explain the action of a transformer.
12. What is meant by a coated filament?
13. A transformer is rated at 10 K.W. The primary is 2400 volts and the secondary 120 volts. Compute the maximum safe current in the primary and the secondary.

TOPICS

New Radio Tubes.	Dynamic Speakers.	Amplifiers.
The Modern Telephone Exchange.	Marconi.	Faraday.

VISUAL AIDS

INDUCED CURRENTS—Eastman Classroom Film.

There are various films which can be secured from the telephone companies covering the fields of the telephone and of radio broadcasting.

EXPERIMENTS

1. Visit a broadcasting station and the telephone exchange.
2. Visit an amateur broadcasting station in the neighborhood.

3. Construct a simple one tube receiver. Some of the references describe the method and give explicit details of construction. Such material can be secured at any radio parts store.

4. The instrument companies can furnish a simple short wave (Fig. 241) transmitting set modeled after the apparatus of Hertz. Try to measure the wave length of the electric wave emitted by the apparatus.

5. Make a study of induced currents.

a. Connect a coil of wire to a galvanometer. Thrust the north pole of a bar magnet into the coil and note the size and direction of the deflection. Pull the magnet out and note the deflection of the galvanometer. Repeat the operation

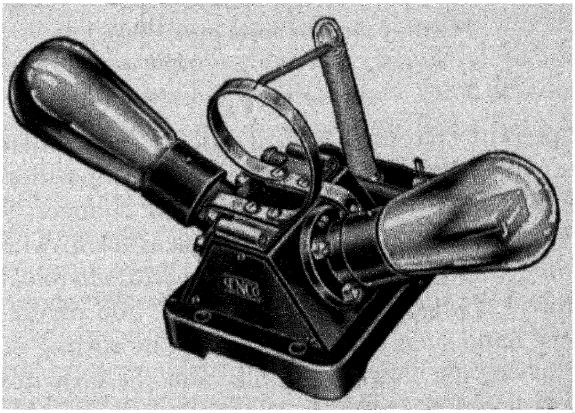

FIG. 241.—A short wave transmitter. (*Courtesy Central Scientific Co.*)

using the south pole of the magnet. Try to make a general statement concerning the current and the direction of motion of the magnet.

b. Construct a transformer by winding two coils of wire on a soft iron bar. One coil may be 100 turns and the other 200 turns. Connect the primary (200) in series with a cell and a key. Connect the secondary to a galvanometer. Close and open the key and note carefully the deflections of the galvanometer. Explain the result.

c. Connect a simple generator (St. Louis type) to a galvanometer. Rotate the armature carefully and watch the galvanometer.

d. If the armature has a split ring (commutator), connect a dry cell to the terminals and operate the machine as a motor. Consult the instructor and the references for details.

21

MATTER ASSOCIATED WITH CHEMICAL ENERGY

"If by fire
Of sooty coal the empiric alchemist
Can turn, or holds it possible to turn
Metals of drossiest ore to perfect gold."
Milton

In the present chapter we shall discuss those phenomena of nature which involve a change in the composition of molecules. Such changes are termed chemical changes, since they involve energy manifested in the chemical form. Many of our most common experiences are associated with chemical changes. By a chemical change we eat, talk, laugh, and digest food. We see on every hand such manifestations as the rusting of iron, the rotting of wood, the souring of milk, and the growth of plants. These are just a few examples of the changes in nature which involve a change in the molecules of the compounds.

Because early man was familiar with these curious facts, he naturally made them the objects of worship and mysticism. In Egyptian times, the priests made use of spectacular chemical experiments in their ritual. Somewhat later came the period of the alchemist. In the hands of the Arabs, alchemy made great progress. An outstanding investigator in this field was Galen who believed that all metals were composed of sulfur and mercury. In all ages man had wished to be able to change metals such as iron and lead into the valuable metal, gold. Anyone successful in accomplishing this feat would have untold wealth. It had long been believed that there existed an "essence" or substance called the "Philosopher's Stone" which had the power of changing lead into gold, of curing all diseases, and of performing other miraculous feats. Many alchemists spent their lives in a search for this elusive stone. (Readers of history will

recall that Ponce de Leon came to Florida in 1512 in an attempt to find the "elixir of life" there.) To this end alchemists worked for hundreds of years purifying materials and, although they did not succeed in making gold, they learned much about the characteristics of the common metals and other elements. It was natural for them to cloak their work in mystery so that they performed many tricks pretending to produce gold. Many kings were duped by them. Even today we often read of some simple soul who turns over his money to a machine which will grind out more.

One good result of the chicanery of alchemy was the rise of iatro-chemistry (the application of chemistry to medicine). The chemicals which had been discovered were now applied to treat disease. Although no universal medicine was found, it opened the way for our modern marvels in medicine.

It is rather interesting for us to read of the medical ideas which were prevalent even as recently as 1850. However, before we scoff we must remember that the bacterial basis for disease had not been discovered at this time. I shall quote from a medical treatise of the period.

"As sure as the cholera will never pass a boundary line—sulphuretted hydrogen, or spread among people with sulphur* in their shoes—so surely it can be said to Yellow Fever—thus far and no further. Just as we recommend fear, care, and sulphur in Asiatic cholera so we recommend fright, run, and charcoal in yellow fever. The substance carrying yellow fever is of a gaseous nature, a miasma, which cannot be spread by the sick. A few handsful of charcoal will absorb the miasma and eliminate all danger."

In the same text the virus of the honey bee was a specific for colds, fatigue, cough, toothache, and apparent death. Carbonate of lime was used for drunkenness, loss of hair, sour food, earache, rheumatism. The metal platinum was a specific for fright, disappointed love, headache, stomach ache, and infant ills. Sulfur was excellent for colds, drunkenness, sour food, snake bite, and catarrh. Lest we laugh too much let us remember that even today many a small boy is dosed with sulfur and molasses.

* Sulphur is now spelled sulfur.

OXIDATION, COMBUSTION, AND REDUCTION

Oxygen, one of the most important of the gases of the atmosphere, is responsible for many changes which are called *oxidation.* Iron rusts because it combines with oxygen, thus forming iron oxide. Coal burns, combining with oxygen to form carbon monoxide and carbon dioxide.

Carbon monoxide is a dangerous gas. When it enters the body by way of the lungs it combines with the red blood corpuscles so that they no longer carry oxygen. If enough corpuscles are rendered inactive, the victim is killed by the gas. It has no color or odor so that it gives no warning of its presence. One should never operate an automobile in a closed garage since part of the exhaust gas is carbon monoxide.

We drive our automobiles by the oxidation of gasoline. We eat food which by oxidation provides energy for our bodies. It must be emphasized that the products of such changes are different from the original materials taking part in the process. If the oxidation is rapid, as in flames or explosions, it is termed combustion. Every science student studies oxidation in connection with mercury. When mercury is heated in an atmosphere containing oxygen, the oxide of mercury is formed. *Mercury plus oxygen yields mercuric oxide.*

In contrast to oxidation we have the chemical change termed *reduction.* This involves a removal of oxygen from a compound. Usually, we mean by reduction such metallurgical processes as the production of tin from tin ore or of iron from iron oxide. Perhaps the best known commercial application of reduction is the blast furnace for the production of iron.

In the furnace (Fig. 242), limestone, coke, and iron ore are arranged in layers. As the mass is heated, the coke (carbon) combines with the oxygen of the iron oxide to form carbon dioxide. The limestone purifies the iron by forming a slag with the impurities.

Thermit welding of the cracks in iron or steel is a very important form of reduction. Aluminum powder is mixed with iron ore and heated. At a certain temperature the aluminum

combines with the oxygen of the iron ore, freeing the iron which flows into the crack thus making a firm joint.

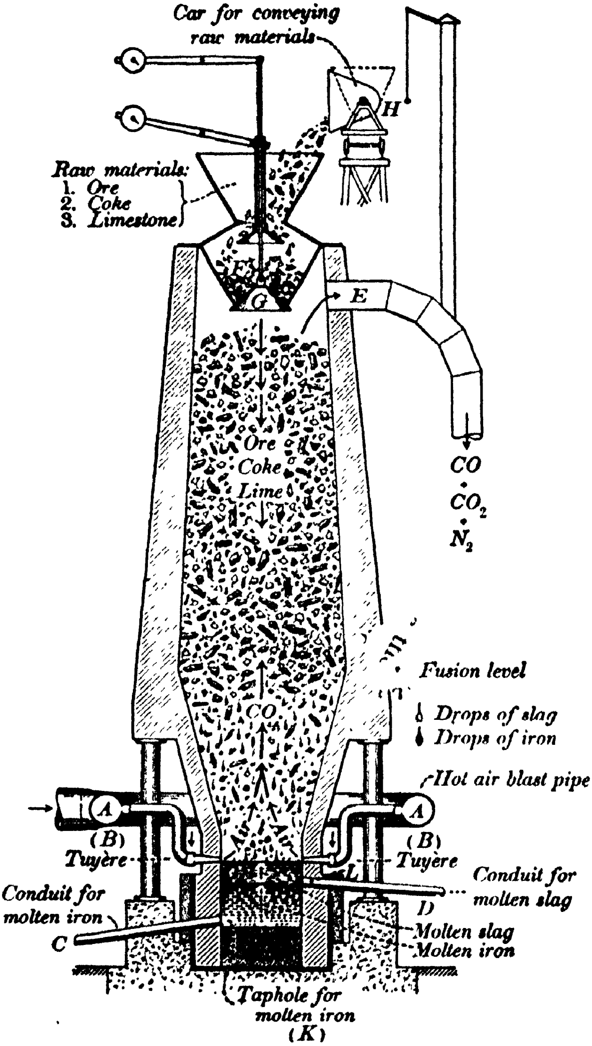

FIG. 242.—The blast furnace. (*From McPherson and Henderson's, "Chemistry for Today," Ginn and Co.*)

Mercury is also used by the student in a study of reduction. When mercuric oxide is carefully heated in a test tube, metallic

mercury will collect in the cool part of the tube. This is ***reduction.*** *Mercuric oxide yields mercury plus oxygen.*

CHEMISTRY AS AN EXACT SCIENCE

Although the science of chemistry is very old, it was not until the 18th century that men began to work accurately by weighing and measuring the substances which they studied. A fundamental principle of chemistry was first stated by Lavoisier (see p. 142). The law states that *in any chemical reaction the combined weight of the substances resulting from the reaction equals the combined weight of the substances taking part in the reaction.* This is the basis of all chemical equations and chemical calculations. In simple language this statement means that if we burn a pound of coal in a weighed amount of oxygen, the weights of the carbon dioxide and ash formed exactly equals the combined weights of the coal and oxygen used. Nothing is lost or gained.

SYMBOLS AND FORMULAS

The old alchemists used to designate the then known elements by odd symbols and pictographs. For instance, the symbol for gold was ☉, for iron ♂, for silver ☽, for water Δ, and for sulfur 🜍. At present we use the first letter of the name of the element and frequently the second or some other letter. For example, there are ten elements whose names begin with the letter C. In order to distinguish them, the chemist uses two letters. C is used for carbon and Cl for chlorine. Some of the elements known in ancient times are designated by letters derived from the Latin name. The symbol for silver is Ag from the word *argentum* (metal of the moon). In a formula, a *symbol* represents *one atom* and *one atomic weight.* O indicates an atom of oxygen, while O_2 represents a molecule of two atoms of oxygen. A list of the known elements and their atomic weights is given in Appendix V.

The chemists have analyzed thousands of compounds and know not only what elements make up the compounds, but the exact proportion of each. Thus H_2O stands for one molecule of water which consists of two atoms of hydrogen and one atom of oxygen. We also know from the formula that water contains 2

parts of hydrogen and 16 parts of oxygen by weight. In other words, 18 grams of water can be made from 2 grams of hydrogen and 16 grams of oxygen.

The chemist has developed a system of equations, a type of shorthand, which he uses to express the changes in structure which take place in chemical reactions. When coal burns we know that the result is heat, ash, and carbon dioxide gas. We may write this as follows: Carbon plus oxygen plus minerals yields carbon dioxide plus ash.

$$C + O_2 \rightarrow CO_2 \text{ (Here the ash is neglected)}$$

Similarly, mercury plus oxygen yields mercuric oxide

$$2Hg + O_2 \rightarrow 2HgO$$

and mercuric oxide yields mercury plus oxygen

$$2HgO \rightarrow 2Hg + O_2$$

and in thermit welding, iron oxide plus aluminum yields aluminum oxide and iron

$$3Fe_3O_4 + 8Al \rightarrow 4Al_2O_3 + 9Fe$$

In the blast furnace, carbon plus iron oxide yields carbon dioxide plus iron

$$Fe_3O_4 + 2C \rightarrow 2CO_2 + 3Fe$$

In some cases we find that two or more elements act as a unit or radical. Some examples of such radicals are NO_3, SO_4, NH_4, and CO_3. When two or more such groups occur in one molecule, the radical is placed in parenthesis with a subscript [$Al_2(SO_4)_3$]. The reason for such units is not known.

It is difficult for the beginner to understand these combinations of figures and symbols. The proper balancing of chemical equations can be acquired only by long experience and by much laboratory experimentation. The beginner should not attempt to memorize complicated equations but should try to understand the scientific basis for the expressions.

ATOMIC WEIGHTS AND VALENCE

The atoms of different elements differ in weight, hydrogen atoms being the lightest and uranium atoms the heaviest. The chemist has assigned to each element an atomic weight—a relative weight. These numbers do not represent the actual weights of the atoms. Oxygen is given the number 16 and sulfur the number 32. This means that sulfur atoms are twice as heavy as oxygen atoms. Such atomic weights are necessary in chemical calculations. Although we now know the actual weights of some atoms, such weights are inconveniently small for use in calculation. The atomic weights are more satisfactory to use.

The binding of atoms into molecules is probably the result of chemical energy. *Valence* is the term which indicates the number of atoms which can be bound to each other. Specifically, hydrogen is said to have a valence of one and oxygen a valence of two, since two hydrogen atoms combine with one oxygen atom to form water. It seems that the maximum valence that any element possesses is eight. Most substances have valences of less than 4.

Since the development of the theories of atomic structure, we have come to believe that the valence of an atom is determined by the planetary electrons in the outer shells of atoms. When sodium combines with chlorine to form salt, a valence electron of chlorine acts as the binding force. In some cases, like atoms unite to form molecules, for example H_2.

IONIZATION

Many scientists have speculated as to the nature of the forces which bind atoms together. Sometimes these forces seem to be very strong, forming stable compounds such as water, while in other cases, as in carbonic acid, the forces seem weak. Some have thought that the forces were magnetic, others believed them to be electrical in nature. Even today, we do not fully understand the nature of these binding forces.

Various experimenters, among them Sir Humphrey Davy, had found it possible to separate compounds by means of an

electrical current. For instance, he found that by passing a current through molten sodium hydroxide (lye) he could produce the metal sodium. Moreover, he found that the metals were always deposited on the negative pole (cathode) of his apparatus. Was there, perhaps, some charge of electricity on the sodium that caused it to be attracted to the negative pole? Perhaps the atomic forces were of an electrical nature. Davy was followed by his famous pupil, Faraday, who formulated the laws which govern the separation of compounds by electricity. This process was named *electrolysis*.

FIG. 243.—Svante August Arrhenius (1859–1927). (*From McPherson and Henderson's, "First Course in Chemistry."* [illegible] *and Co.*)

Despite the great advance made by Faraday, it remained for Svante Arrhenius (Fig. 243), a Swedish chemist, to bring forth in 1884 the theory of ionization which offered for the first time a satisfactory explanation of the experimental results of the scientists who had preceded him. He assumed that there were two kinds of compounds: those which like salt in water conducted electricity, and another type like sugar, which when dissolved in water did not make the water a conductor. His theory assumed that, if salt (NaCl) is dissolved in water, some of the salt molecules separate into positive ions of sodium $(Na)^+$ and negative ions of chlorine $(Cl)^-$. Each of these ions may gather to itself several molecules of water and these units drift through the water. On the other hand, it may be that the water molecules have a great attraction for sodium atoms, tearing them away from the salt molecules. *An ion is believed to be an atom or a group of atoms having an excess electrical charge, either positive or negative.* This charge is due to the electrons outside the nucleus of the atoms. Since a sodium atom has 11 electrons about the nucleus, a positive sodium ion would have only 10 electrons. A negative

chlorine ion having gained an electron would have 18 instead of the normal 17. The water molecules themselves ionize but little, usually acting as a medium in which ionization takes place. A positive ion has lost electrons while a negative ion has gained them. An example of a group of atoms acting as an ion is the $(NO_3)^-$ radical. Since a hydrogen atom consists of a proton and an electron, a positive hydrogen ion will be a proton only.

Ions have entirely different properties from the original atoms or molecules. For instance, when hydrogen chloride is

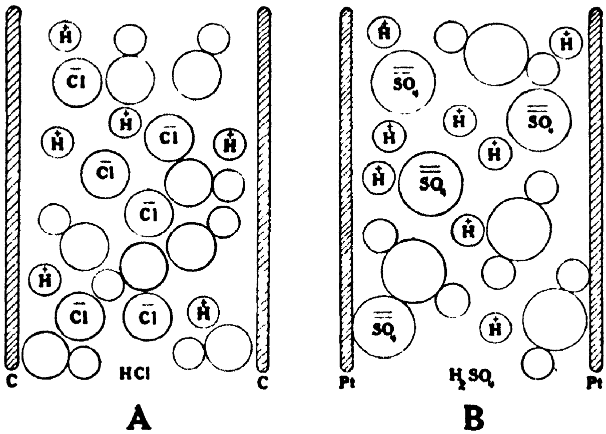

FIG. 244.—Diagrammatic representation of ionization. In (A) HCl is dissociated into $\overset{+}{H}$ ions and $\overset{-}{Cl}$ ions. In (B), H_2SO_4 is dissociated into $\overset{+}{H}$ ions and $\overset{=}{SO_4}$ ions. (*Weld and Palmer.*)

dissolved in water, hydrogen ions and chlorine ions result (Fig. 244). Although chlorine gas is greenish and forms a pale yellow solution when the gas is dissolved in water, water containing chlorine ions is colorless. Hydrogen ions combine with a number of organic dyes forming colored compounds. A red compound is formed with litmus, so that we can always identify hydrogen ions with litmus solution. When phenolphthalein is added to an acid solution it forms a colorless compound, but in the presence of a base it forms a red compound. Many other substances form colored compounds in the presence of acids or bases. These compounds are called indicators and are used to indicate the

acidity or basicity of a solution. Hydrogen chloride dissolved in benzine, or citric acid crystals dissolved in absolute alcohol will not dissociate into ions; indicators do not change when added to these solutions. This proves that ions rather than molecules are responsible for the change in color of the indicators.

ELECTROPLATING. If two electrodes connected to a source of electrical current are immersed in a solution containing ions, the positive ions drift toward the negative pole (cathode) and the negative ions drift toward the positive pole (anode). If we wish to plate a spoon with silver, we make the spoon the negative pole of the apparatus and use a bar of silver as the anode (Fig.

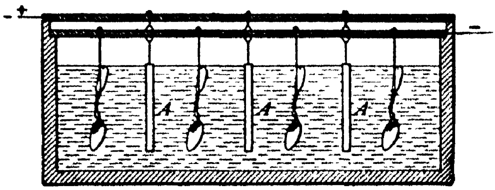

FIG. 245.—Electroplating. The process of plating a spoon with silver. (*From McPherson and Henderson's, "Chemistry for Today," Ginn and Co.*)

245). As the current flows through the solution of some silver salt, the silver ions deposit as metallic silver on the spoon. As long as the current flows, the silver will spread itself over the spoon and the silver bar will lose silver. At the present time, many metals are deposited in this way. We have chromium plating on our automobiles, gold plated jewelry, and nickel plated utensils.

ACIDS

Some common acids are sulfuric acid (H_2SO_4) used in storage cells, acetic acid ($HC_2H_3O_2$) in vinegar, and citric acid ($HC_6H_5O_7$) in lemons and grapefruit. These substances have a sour taste, turn blue litmus red, and most of them react with metals. This latter characteristic explains why tomatoes will brighten the iron or aluminum pan in which they are cooked. Acids contain hydrogen and one or more non-metals. When dissolved in water they dissociate into hydrogen ions and non-

metallic ions. In the case of hydrochloric acid the equation is as follows:

$$HCl \rightarrow H^+ + Cl^-$$

Weak acids dissociate to a very slight extent, consequently they form very few ions. The acids in tomatoes, citrus fruits, and soda water are weak. Other acids dissociate as much as 92% or more, thus forming many hydrogen ions. These are strong acids of which sulfuric, hydrochloric, and nitric acids are examples. (Of course, in a very dilute solution of even a strong acid there can be but few ions present.) We have a very dilute solution (about .4%) of hydrochloric acid in the stomach as a part of the gastric juice. Vinegar contains acetic acid and, in addition to its aromatic flavor, it is used because of the acid characteristic of a sour taste. Vinegar, lemon juice, and oxalic acid are used in neutralizing stains. Boric acid is very mild and is used as an antiseptic and eyewash. Sulfuric acid, while not as strong as hydrochloric, has the ability to destroy skin, clothing, and wood, because of its affinity for water. It is a dangerous acid. (*This acid should always be added to water, never the reverse.*)

BASES

Bases contain a metal and one or more hydroxyl ions $(OH)^-$. The hydroxyl group consists of an atom of hydrogen and one of oxygen which are attached to each other and act as a unit in chemical reactions. Bases have a bland taste and a slippery feeling. When they are dissolved in water they dissociate into metallic ions and hydroxyl ions, the latter being negative. The hydroxyl ions turn red litmus blue.

$$\underset{\text{sodium hydroxide}}{NaOH} \rightarrow \underset{\text{sodium}}{Na^+} + \underset{\text{hydroxyl}}{OH^-}$$

One of the strongest and also one of the most dangerous bases is household lye, sodium hydroxide. It should be kept out of the reach of children because of the fact that they sometimes eat it. Ammonia is a water solution of ammonia gas and, although it does not contain a metal, it is classed as a base. Lime-

water is calcium hydroxide, a weak base. Milk of Magnesia contains magnesium hydroxide, another base. All compounds, whether bases or salts, which when dissolved in water turn red litmus blue, are called alkalies. Alkalies dissolve grease and are used for cleaning purposes.

SALTS

There is no more amazing experiment in science than the formation of a salt by the interaction of an acid and a base. If the experimenter adds a little phenolphthalein to a dilute solution of hydrochloric acid and then, drop by drop, introduces a solution of sodium hydroxide, after a time the solution will turn pink indicating that it is basic (Fig. 246). If more hydrochloric acid is added until the color just disappears and the solution is evaporated to dryness, the crystals will be found to be sodium chloride. The neutralization of hydrochloric acid by sodium hydroxide has produced a salt, a substance different from either the acid or the base.

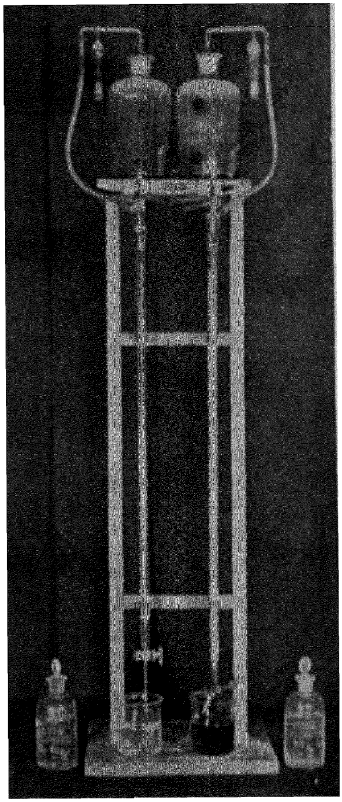

FIG. 246.—Neutralization apparatus. An acid and a base are mixed to form a salt. In the beaker is an indicator whose color indicates the basicity of the solution.

Salts are formed when acids react with bases and they consist of the metal of the base and the negative ion of the acid.*

Base plus acid		yields	salt plus water	
$NaOH$ +	HCl	$\rightarrow$	$NaCl$ +	H_2O
sodium hydroxide	hydrochloric acid		sodium chloride	water

* Salts may be formed in other ways.

They have a characteristic salty taste, many of them being neutral to litmus. Common household salts are table salt, borax, washing soda, baking soda, Epsom salts, sodium phosphate, and soap.

SOME COMMON HOUSEHOLD CHEMICALS

Substance	*Common Name*	*Formula*
Copper Sulphate	Blue Vitriol	$CuSO_4$
Iron Sulphate	Copperas	$FeSO_4$
Potassium nitrate	Nitre	KNO_3
Sodium nitrate	Saltpetre	$NaNO_3$
Magnesium sulfate	Epsom salts	$MgSO_4$
Sodium carbonate	Washing soda	Na_2CO_3
Ammonium chloride	Sal ammoniac	NH_4Cl
Sulfuric acid	Oil of vitriol	H_2SO_4
Hydrochloric acid	Muriatic acid	HCl
Sodium sulfate	Glauber's salt	Na_2SO_4
Boric acid	Boracic acid	H_3BO_3

Water dissociates to a very small extent into hydroxyl and hydrogen ions. These ions may interact with the ions of other substances. When washing soda or baking soda are dissolved in water, some molecules react with the ions of the water to produce carbonic acid, a very weak acid, and sodium hydroxide, a strong base. For this reason the solution acts like a base.

In this connection it is of interest to correct the fallacious idea that people afflicted with indigestion take baking soda to neutralize the excess acid in the stomach. The real effect of sodium bicarbonate and most other digestive agents is to stimulate the opening of the pylorus so that the stomach can empty normally.

CHEMICAL ENERGY IN WARFARE

Modern warfare is largely a display of high powered explosives and poison gases. The World War was really a war of chemists.

The oldest explosive is gunpowder, made from potassium nitrate, sulfur, and charcoal. The disadvantage of gunpowder is the large amount of smoke produced. This substance has been largely replaced by nitrocellulose (smokeless powder). Nitrocellulose is made by treating cellulose with a mixture of nitric and sulfuric acids. (See Chapter 26.) The material, called guncotton, is dissolved in acetone and made into rods and powder grains.

Another powerful explosive is *nitroglycerin* ($C_3H_5N_3O_9$). If glycerin is treated with nitric and sulfuric acids an oily liquid is produced which is dangerously explosive. (Every teacher of elementary chemistry should be on the lookout for schoolboy attempts along this line.) It occurred to the Swedish chemist Nobel, the founder of the Nobel prize, to dissolve guncotton in nitroglycerin. This produced a solid called "*cordite*," which is a standard high explosive.

Still another type of explosive is made by nitrating the organic liquid, toluol. This gives us, *tri-nitro-toluol* ($C_7H_5N_3O_6$), which is popularly called "T.N.T." This substance was first used in warfare by Germany in 1914, and was so effective that the great fortifications of Belgium crumbled almost as if by magic. The armies were forced from forts into trenches. T.N.T. is perhaps the best of all high explosives. It is insensitive to ordinary shocks so that it can be handled with safety. In order to make it explode, it is necessary to use mercury fulminate to start the explosion. Each of the explosives described contains nitrogen, that atmospheric gas which is inert in the natural condition and very active when in the combined state.

Despite the superiority of Germany's artillery at the outset of the war, both sides had reached a stalemate during the winter of 1914. In order to regain the advantage, Germany resorted to poison gas. In April 1915, she laid down a row of tanks of liquid chlorine in the battlefield of Ypres. Waiting for a favorable wind, they released the gas and the cloud rolled over the allied trenches. The soldiers were unprepared for such an attack and were demoralized. From that time, poison gas was a weapon of both sides. The chemists were kept busy making new gases and

devising gas masks to protect the troops from them. After chlorine, *phosgene* ($COCl_2$) was used. This gas is made by mixing chlorine and carbon monoxide in the light. It can be easily liquified and is very poisonous. It was one of the most destructive of all gases used. Other gases were *chloropicrin*, (which caused vomiting), *sneeze gas*, and *tear gas*, the latter two being used by the police authorities of today in subduing criminals.

However, the most disastrous of all substances used as poison was *mustard gas.* Actually the substance is a liquid and when sprayed on the ground it lingers, slowly evaporates, and poisons the surroundings for days. The gas attacks the skin, eyes, and lungs. Many soldiers died from pneumonia from the effects of the gas.

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PROBLEMS

1. State 5 facts about each of these formulas. $NaCl$, H_2SO_4, Na_2CO_3, $Al_2(SO_4)_3$, $Ca(OH)_2$.
2. What are the symbols for oxygen, carbon, sodium, nitrogen, gold?
3. How do atoms differ from ions?
4. How do acids differ from bases?
5. Why do some salts have an alkaline reaction?
6. What is the difference in structure between hydrogen and oxygen? Sodium and salt?
7. Name several common household chemicals.
8. What is meant by valence?
9. What is electrolysis?
10. What is meant by nitration of a substance?

TOPICS

Indicators. Explosives. Ancient Drugs. Metallurgy.
Dentifrices which neutralize "acid mouth."

VISUAL AIDS

OXIDATION AND REDUCTION—University of Chicago Film.

ELECTROCHEMISTRY—University of Chicago Film.

THE ARRANGEMENT OF ATOMS AND MOLECULES IN CRYSTALS—General Electric Co.

EXPERIMENTS

1. *Acids*. Place a few drops of vinegar or acetic acid into half a test tube of water. Test with litmus. Pour a few drops of this solution into a clean beaker of water and cautiously taste it. Cover a small piece of zinc in a test tube with dilute hydrochloric acid. What gas is given off? What have you learned about the properties of acids from this experiment?

2. *Bases*. Add a few drops of sodium hydroxide solution to half a test tube of water. Test with litmus. Feel a few drops between the fingers. (Wash your fingers with water. Do not wipe them on clothing.) State two properties of bases.

3. *Salts*. Dilute 1 cc. of concentrated HCl with 9 cc. of water. To 5 cc. of this diluted acid add 5 cc. of sodium hydroxide solution. (Assuming that the HCl, concentrated, is 13 Normal, a stock solution of NaOH of the same strength as may be made by dissolving 52 grams of NaOH in 1000 cc. of water.) Test the resulting mixture with litmus. Add, drop by drop, enough of either acid or base to make the solution neutral Pour a few drops of the solution into a watch crystal, placing the crystal over a beaker of boiling water. When the water has evaporated, leaving crystals of the salt, compare your crystals with crystals from the stock bottle of NaCl. If possible, examine the crystals under a microscope.

4. *Indicators*. Use a few drops of each substance in the left hand column in half a test tube of water. In the case of liquid indicators, add 2 drops of indicator to each tube. Record the resulting color in the chart.

Substance	*Litmus*	*Methyl Orange*	*Phenolphthalein*	*Methyl Red*
HCl				
Na_2CO_3				
$Al_2(SO_4)_3$				
NaOH				
NaCl				

22

CHEMISTRY ASSOCIATED WITH LIVING THINGS

"*The citizen of our day uses modern science at each turn of his day's work.*"
Caldwell

IN THE previous chapter we have described some of the interesting phenomena associated with the so-called inorganic substances. In the present chapter we shall discuss some of the common materials produced and used by living substances.

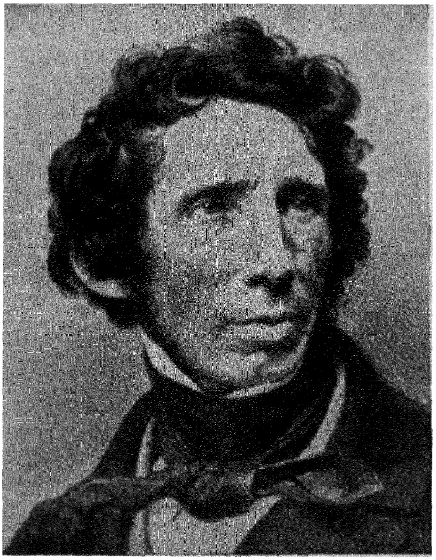


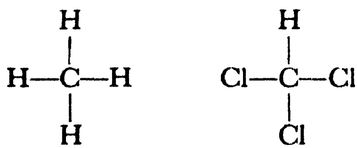
FIG. 247. Frederick Wöhler (1800–1882). A famous German chemist. (*Hackh.*)

Although herbs and roots had been used in the treatment of disease for many centuries, it was not until the nineteenth century that Wöhler (Fig. 247) in 1828, accidentally produced *urea*, a constituent of urine, in the laboratory. (About one ounce of urea is excreted by normal man each day.) Until this

time man had assumed that a gulf was fixed between ordinary chemicals and those substances which were produced by living organisms (plants and animals). Previously, men had always believed that some vital (living) force was necessary to produce organic compounds.

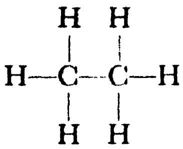
Wöhler's discovery led to the science of organic chemistry. Such great progress has been made during the last century that up to the present several hundred thousand such compounds have been prepared. It is beyond the scope of this text to explore the mazes of organic chemistry. We shall content ourselves by describing a few substances that everyone knows, either in the home or in the drug and department stores. It must be emphasized however, that there is no real difference between organic and inorganic substances.

It was early discovered that carbon was the heart of all organic substances. In these substances carbon has a valence of four. It is said to have four bonds. This means that one atom of carbon can unite with four atoms of hydrogen or with two of oxygen. Moreover, the chemist can replace one of the combining atoms with others, thus forming new substances. In this statement lies the mystery of *organic synthesis* (the building up of complicated substances from simpler ones). An example of this synthesis is the anesthetic, chloroform. If one begins with the gas methane (CH_4) and replaces 3 of the hydrogen atoms by chlorine atoms we form chloroform ($CHCl_3$). The chemist uses a graphical method of representing the reaction

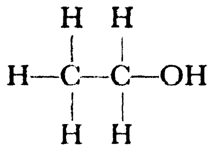


methane (CH_4) chloroform ($CHCl_3$)

It has also been found that two or more carbon atoms can exist in a molecule, in which case the carbon atoms have mutual bonds. Interesting examples are ethane and ethyl alcohol (C_2H_5OH). By replacing one hydrogen atom of ethane by a hydroxyl radical we may produce alcohol.



ethane

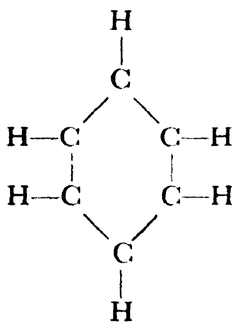


ethyl alcohol

Another important structural formula needs to be mentioned — the *benzene ring*. When coal tar is distilled the chemist derives a series of compounds called *aromatics*. Among these are benzene, naphthalene, toluene, xylene, phenol, and anthracene. Most of these substances are well known, naphthalene being used in moth balls, and phenol (carbolic acid) as an antiseptic.

One ton of coal yields about 100 pounds of coal tar. This tar will yield 10 pounds of benzene, 2 pounds of toluene, $\frac{1}{2}$ pound of phenol, and $\frac{1}{2}$ pound of naphthalene. From these compounds are produced several hundred *intermediates* which upon further chemical synthesis yield thousands of dyes. Figure 76 shows schematically the great variety of coal products.

Benzene (not to be confused with the benzine used as a gasoline) has the formula C_6H_6. The chemist, Kekulé, constructed a hexagonal formula for the compound.* Each line represents a bond.



DYES AND PERFUMES

In 1856, Perkin, (Fig. 248), a 17 year old chemist, was trying to make quinine from aniline. To his surprise his result was a

* It is worthy of note that X-ray studies justify the structural formula for benzene.

black mass which, when dissolved in alcohol, made a beautiful violet liquid. He named it "mauve." Following up his discovery he was able to produce the substance identical with alizarin, a turkey red dye, by the synthesis of anthracene. Up until this time the production of alizarin had been a French monopoly, being produced from the madder root. As a result of the new synthesis, red dye became very cheap and the madder root market was

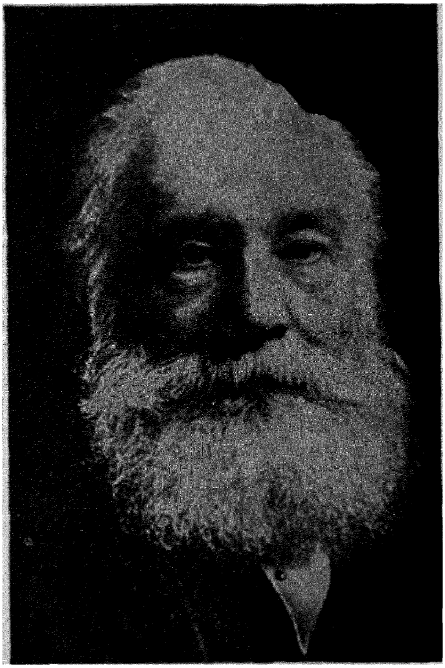


FIG. 248.—Sir William Perkin (1838–1907). (*From Moore, "History of Chemistry," McGraw-Hill Book Co.*)

ruined. German chemists now took up the study of dyes and produced a great variety of colors. To do this they worked out the structural formulas so that they did not need to work blindly. Some of the results were that cochineal bugs were replaced by azo-scarlet; indigo, originally produced in India from the indigo plant, was prepared from the coal-tar compound, naphthalene.

Every reader of history is familiar with Tyrian purple, the symbol of royalty in the Roman empire. This dye was extracted

from shell fish along the coast of Tyre, hence the name. By analyzing this substance, scientists were able to build a better purple than the original. Each year we see new dye shades advertised. Nearly all of these dyes have had their origin in the humble, messy, coal-tar.

Moreover, most of our flavoring materials are now produced artifically from coal tar. We have such flavors as almond, banana (amyl acetate), vanilla, wintergreen (methyl salicylate), peppermint, and pineapple (ethyl butyrate). Actually, lemon is probably the only flavor derived from the plant for which it is named. Even the perfumes are synthesized. The perfumes giving the delicate odors of heliotrope, lilac, rose, and orange blossoms are all produced synthetically. Truly coal-tar is a magic substance!

DRUGS

As we might expect, drugs were used in very early times. The ancient Egyptians used castor oil, aloes, peppermint, anise, juniper berries, and wormwood. Mixtures of these drugs were used for many purposes, including such diseases as cancer, tuberculosis, and kidney disease.

By the end of the 15th century, physicians had greatly increased the drug list and were prescribing senna, camphor, rhubarb, opium, cloves, pepper, and ginger. Somewhat later we find references to balsam, lemonade, sarsaparilla, and quinine. Most of our vegetable laxative drugs were used by the American Indians before Europeans settled in North America.

In the field of pharmacology, the chemist has made great progress. We are bombarded over the radio and by newspapers with the advertising of innumerable drugs. Many of these are synthetically produced in the laboratory. Probably the best known drug is quinine, made from the bark of the chinchona tree which grows in South America. This drug has the curious property of killing malaria parasites in the blood stream. It is a specific for malaria, and travelers in the tropics use it daily. In moderate doses, it seems to have no ill effects on the human body. Quinine has been produced artifically, but the cost of production is still too great to compete with the natural product.

We all know the drug aspirin (acetyl-salicylic acid) which is prepared from phenol. This synthetic substance, together with its twin, salol (phenyl salicylate), relieves congestion, neuralgia, headache, and rheumatism. It is necessary to guard against excessive use of these drugs. They affect digestion and slow up heart action if taken in large quantities. Some other synthetic drugs which we all know are novocaine (an important drug replacing the dangerous drug cocaine), mercurochrome, salvarsan, formaldehyde, and saccharin.

It is said that the most common American disease is constipation. We have become a nation of drug users in attempting to alleviate this digestive condition. Most purgatives have the property of causing more water to enter the intestine. Probably the most common of the drugs is magnesium sulfate (Epsom Salt). The presence of this salt in the intestine causes water to flow in through the walls due to osmosis. A strong salt solution in the intestine and water outside the wall produce an osmotic pressure which tends to dilute the salt solution (see p. 401). The salt also produces some irritation.

Other drugs such as calomel and castor oil are intestinal stimulants, due to their irritating properties. Such drugs must be used with caution. In addition, there is a whole series of vegetable drugs which have the property of causing peristalsis —senna, jalap, gamboge, podophyllum, and phenolphthalein. It is important to emphasize that no drug will cure the difficulty. Most of them will in time cause the intestine to be less active, so that stronger doses must be taken.

Another false impression is that all vegetable drugs are harmless. This is entirely wrong. Some of the most dangerous drugs are of vegetable origin. Phenolphthalein, the essential ingredient of many laxatives, is a poison and will in time cause severe intestinal irritation.

TOILET PREPARATIONS

There are a great number of materials which are classed as toilet preparations. These include face creams, face powders, depilatories and deodorants. All of these products are made from

a rather limited number of chemical compounds, most of them well known. It is curious that the Food and Drugs Act does not regulate such products. Many of them contain injurious chemicals. Such materials should be purchased with caution.

Face creams contain some of the following: wax, borax, rosewater, oil of almonds, glycerin, zinc oxide, and perfume. Unfortunately, the contents of such preparations are not printed on the container. Some contain poisonous drugs, especially the freckle removers.

Face powders contain such chemicals as salicylic acid, talc, zinc oxide, starch, and chalk. None of them are harmful unless coloring matter is used, in which case irritation may result. Rouges contain cochineal, chalk, talc and gum-arabic.

We are bombarded over the radio with advertising of an amazing variety of preparations for cleaning the teeth. It is important to remember that there are no mysterious new compounds in any of these preparations. Nearly all contain some form of soap, some antiseptic, and some material which acts as an abrasive.

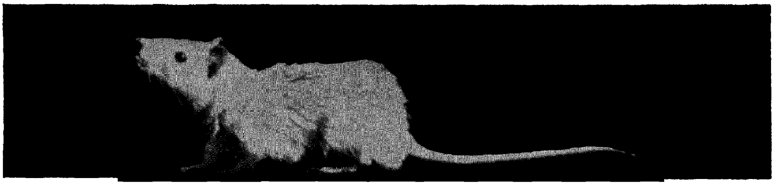
Non-perspirants and deodorants are used to prevent the flow of perspiration. They do this by some astringent which closes the pores of the skin. As is to be expected, alum and boric acid are the two most common ingredients.

FOODS AND THE DIGESTION OF THEM

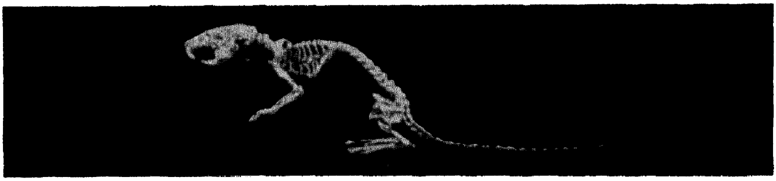
Foods are those things which are consumed by living things to maintain health and growth. A healthy diet must possess the following characteristics: It must contain the proper amount of the various chemical substances. It must be adapted to the climate, to the age of the individual, and to the amount of work done by him. Moreover, it must be present in a digestible form (Fig. 249).

CARBOHYDRATES. Among the most important of human food materials is the great class of *carbohydrates* which includes the *sugars*, the *starches*, and *cellulose*. The carbohydrates, as the name indicates, are composed of carbon, hydrogen, and oxygen. Perhaps the most important of the sugars is sucrose ($C_{12}H_{22}O_{11}$)

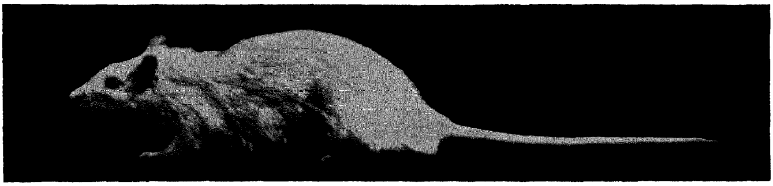
which is manufactured from sugar cane and sugar beets. It is the sugar we know best. Cows' milk contains lactose (milk sugar). In



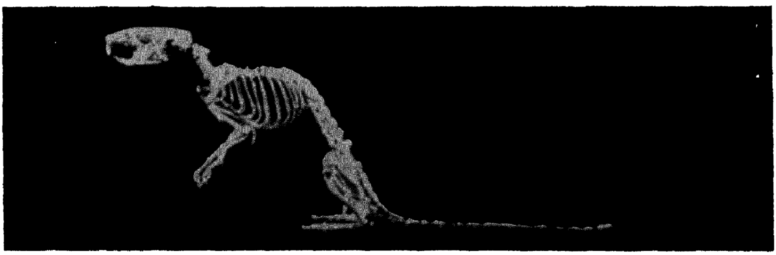
This rat ate only meat, potato, bread and butter. He weighed 89 grams.



His bones also show the effect of poor diet.



This rat ate plenty of milk and vegetables, besides meat, potato, bread, and butter. He weighed 194 grams.



His bones are strong and well formed.

FIG. 249.—Growth may be controlled by diet. Food made the difference in these twin brothers, 6 months old. (*Bureau of Home Economics, U.S. Dept. of Agr.*)

honey and fruits we find dextrose. Dextrose is not as sweet as sucrose but is just as nutritious.

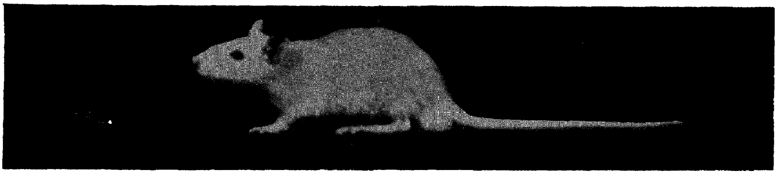
Most plants contain the carbohydrates, starch and cellulose. We find starch in potatoes, wheat, corn, and oats. The starch is enclosed in cells of cellulose having rather tough walls. Consequently, it is necessary to cook starch to break down the cell walls so that the digestive juices can act on the starch itself. In bread making the flour is mixed with water, sugar, and yeast. The group of enzymes called yeast cause the sugar to ferment to alcohol, liberating carbon dioxide. The gas causes the loaf to expand and upon baking we have a light spongy mixture of digestible starch. The alcohol is expelled by heating.

FATS. The principal fats are lard, olive oil, butter, cotton-seed oil, and tallow. Fats are classified as fats of animals, such as lard and tallow, and vegetable fats or oils which include palm, cocoanut, peanut, cotton-seed, corn, olive, and cocoa oils. The liquid fats contain the salt *olein* which is unsaturated. In the presence of a catalyst such as nickel dust, olein will combine with hydrogen atoms to form the solid fat *stearin*. "Crisco" is made in this way. Most fats are mixtures of the salts *olein*, *palmitin*, and *stearin*. They have the technical name *esters*.

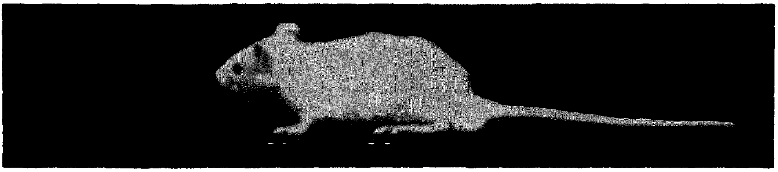
The body has the ability to store fats in the muscles of the various organs so that the animal can endure periods of famine. Animals such as bears, which hibernate in winter, store great layers of fat in the summer which sustains them in the winter. Humans who eat to excess often store unwanted fat! Fats are a valuable food and are rather expensive.*

PROTEINS. Proteins are slimy, gelatinous, substances which are essential for cell growth in the body. Some familiar ones are egg albumin, gluten of wheat, and casein of milk. So far the chemist has not been able to produce proteins in the laboratory. It is certain that the chemical changes of proteins are some of the fundamental characteristics of life. Proteins contain carbon, hydrogen, nitrogen, oxygen, and sometimes sulfur and phosphorus. The molecular structure is very complicated so that the exact formula is a matter of conjecture. Proteins break down into amino acids which are utilized in the body (Fig. 250).

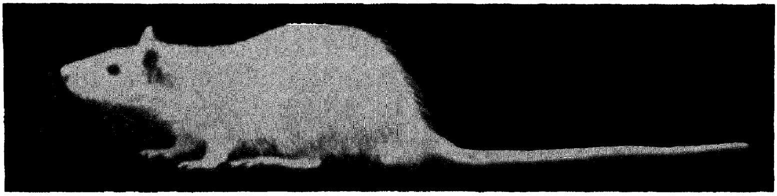
* Just recently, fats have been synthesized from hydrocarbons.



This rat had good protein but not enough. It weighed 70 grams.



This one had enough protein but of a poor kind. It weighed only 65 grams.



This one had good protein and plenty of it. It grew normally and weighed 193 grams.

Good Protein Foods. Milk, all forms—Eggs—Poultry, all kinds—Cheese—Meat, lean, all kinds—Fish—Shellfish.

FIG. 250.—Protein for building muscles and all tissues. Rats from the same litter, 11 weeks old. (*Bureau of Home Economics, U.S. Dept. of Agr.*)

Foods that are rich in proteins tend to exert an acidic effect in the body because a number of the end products are acids. On the other hand, fruits and vegetables generally exert an alkaline effect due to the fact that they contain salts of calcium, sodium, and potassium. The acids are burned up in the body and the metallic salts (e.g. sodium citrate) exert a basic effect in the body. It is rather anomalous that some acid fruits have an alkaline effect in the body.

TABLE OF FOOD VALUES, PERCENTAGE BY WEIGHT

	Protein	*Carbo-hydrate*	*Fat*	*Crude Fiber*	*Ash*
Beans (dry)	22.5	60.0	1.8	4.4	3.5
Lettuce	1.2	2.9	0.3	0.7	0.9
Peas, green	7.0	16.9	0.5	1.7	1.0
Tomatoes	0.9	3.9	0.4	0.6	0.5
Apples	0.4	14.2	0.5	1.2	0.3
Oranges	0.8	11.6	0.2	..	0.5
Bread (white)	9.2	53.1	1.3	0.5	1.2
Oatmeal	16.1	67.5	7.2	0.9	1.9
Rice	8.0	79.0	0.3	0.2	0.4
Walnuts (English)	18.4	13.0	64.4	1.4	1.7
Beef Steak	18.9	....	18.5	...	1.0
Eggs	13.4	....	10.5	...	1.0
Butter	1.0	....	85.0	...	3.0
Cheese (Amer.)	29.0	0.3	36.0	...	3.4
Milk (whole)	3.3	5.0	4.0	.	0.7
Molasses	2.1	69.3	....	..	3.2
Olive Oil	0	0	100	0	0

DIGESTION. Carbohydrates, fats, and proteins supply the energy for the body. These materials are oxidized by the oxygen taken in by the lungs, thus producing body heat. If a carbohydrate such as dextrose is oxidized, carbon dioxide and water are formed.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

When a fat such as stearin undergoes oxidation the equation is as follows:

$$2C_{57}H_{110}O_6 + 163O_2 \rightarrow 114CO_2 + 110H_2O$$

The digestion of food is carried on by the aid of the catalysts called enzymes. Enzymes are not molds or bacteria. They are lifeless, colloidal substances present in animal and vegetable tissue.

BODY CATALYSTS

There are three very interesting groups of catalysts in the human body—digestive enzymes, hormones, and vitamins. They are present in such traces that many of them have remained unsolved mysteries until very recently—in fact, some have not yet been completely identified. Just as traffic officers maintain an orderly flow of traffic, these catalysts maintain an orderly metabolism.

ENZYMES. Enzymes aid in digestion of food. We eat a great variety of chemical compounds in our foods, many of these compounds being very complex, and insoluble in water. Digestion is necessary to break foods into a few simple substances which are soluble in water. In order for us to derive energy, growth, and maintenance from our food it must dissolve in water and pass through our intestinal wall into the blood by osmosis. When we stop to consider that our body cells—the cells in the tip of the finger, for instance, are too small to be seen without a microscope, and that these cells must convert the molecules of food into molecules of body substance, and must burn food for its energy, we can readily understand why digestion is necessary.

Our digestive juices are classified into three groups, salivary, gastric, and intestinal juice.

SALIVARY DIGESTION

The principal digestion taking place in the mouth is the conversion of starch to simple sugars. Starch molecules are very large, the smallest starch molecules having the probable formula $C_{1200}H_{2000}O_{1000}$. They are either insoluble or very slightly soluble in water, depending upon their size, but even the smallest are too large to pass through the intestinal wall.

To change starch to sugar in the laboratory, it is necessary to boil with hydrochloric acid (about 5%) for twenty or thirty minutes. In the mouth, however, we can change starch to sugar

in less than sixty seconds, without boiling. An enzyme called ptyalin acts as the catalyst to bring about this astonishing change.

EXPERIMENT. To change starch to sugar.

Add a few cubic centimeters of Benedict's reagent to some soda cracker crumbs in a beaker of water. Bring to a boil. The solution should remain clear and unchanged in color. Chew half a soda cracker for 60 seconds, expectorate it into a beaker, add water and Benedict's reagent. Bring to a boil. A brick-red precipitate results, showing the presence of sugar. The large starch molecules have been broken down to comparatively small and simple molecules.

In addition to ptyalin, saliva contains maltase, which also aids in sugar formation. No other digestion takes place in the mouth.

GASTRIC DIGESTION

Gastric juice contains three enzymes: rennin, which curdles milk; pepsin, which changes protein to simpler proteins known as peptones; and a small amount of lipase, which converts emulsified fats (such as are in milk and mayonnaise) to fatty acids and glycerin. There is a half of a percent of hydrochloric acid in gastric juice. One of its several functions is to aid in the digestion of protein. It also splits disaccharides, such as cane sugar, to monosaccharides.

Simple sugars, alcohols and some drugs (aspirin being one) are absorbed directly from the stomach into the blood, but the large mass of food is retained for one or more hours, being passed into the intestine very gradually.

INTESTINAL DIGESTION

Digestive juices from three sources carry on intestinal digestion.

1. Pancreatic juice is secreted by the pancreas, a small gland lying back of and below the stomach. It contains sodium carbonate (to neutralize the gastric acid), trypsin (to split hitherto undigested proteins to peptones), steapsin (to digest fats), and amylopsin (to digest starch).

2. Bile, secreted by the liver, does not contain any enzymes but accelerates digestion and solution of fats.

3. Intestinal juice is formed in the walls of the intestine itself. It contains erepsin (splits peptones to amino acids) and three,

enzymes which complete carbohydrate digestion. (Maltase, sucrase, and lactase.)

Iron, calcium, phosphorus are needed.

VITAMINS

The vitamins are nutritional factors found in very small amounts in foods, which perform a specific nutritional function. Their discovery constitutes one of the most startling and dramatic pages in nutritional history.

Prisoners in the Bilibid prison in Manila used to eat "low-grade" brown rice. American Army officers tried to better the prison fare by substituting white polished rice. Beriberi, a nervous paralysis formerly common in the Orient, broke out in the prison and was checked only when the diet was changed.

Whether experimental animals live or die depends upon whether diets, good in other respects, contain butter or lard. Infants develop rickets unless certain natural fats are included in their diets—but if these natural fats are purified they fail to protect against rickets!

Vitamins are present in such minute amounts that they have been isolated and identified with the greatest difficulty. Our daily requirement is so small that dosage is not measured in pounds, ounces, or even grams, but in "units" which protect against the specific deficiency. They are designated by letters, because their chemical identity was discovered so many years after their nutritional functions.

As was mentioned in connection with enzymes, complicated chemical changes must take place in the body without the benefit of either high temperatures or strong reagents. Each vitamin serves specific catalytic functions in the body, thus enabling chemical changes to take place quickly, without strong reagents and at body temperatures.

Vitamin A promotes growth, helps to maintain a healthy respiratory tract, prevents an eye disorder called ophthalmia, maintains the integrity of the epithelial and nerve tissues, and aids in reproduction (controls ovulation). It has long been known, for instance, that milk and eggs (good sources of vitamin

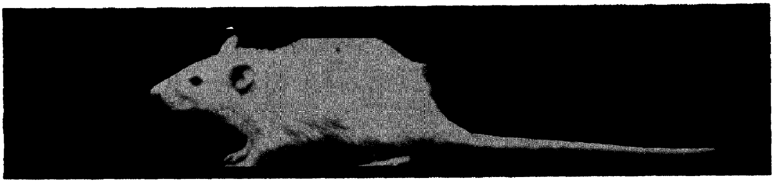
VITAMINS

·	*Sources in Diet*	*Artificial Sources*	*Deficiency Effects*	*Results from Use*	
A	Carrots, spinach prunes, butter, liver	Fish liver oil	Loss of appetite, eye trouble, colds and respiratory ailments	Good appetite, resistance to infection	Has been synthesized in the laboratory
D	Sea foods Very little in vegetables	Cod liver oil, irradiation of ergosterol and fats	Rickets, bad teeth, constipation	Proper metabolism of calcium and phosphorus, good bone structure	
E	Cereals, lettuce, spinach, milk, eggs, meat	Wheat germ, oil and lettuce leaves	Reproductive sterility		
C	Peppers, spinach, peas. tomatoes, lemons, oranges, raw milk, liver	By synthesis	Scurvy, colds, poor bone structure	Resistance to infection, good bone	Has been synthesized, destroyed by heating in air
B_1	Whole cereals, vegetables, oranges, · prunes, milk, egg yolk	Baker's yeast	Beriberi, colds, poor digestion	Good appetite and digestion, resistance to infection	Formula and structure known
B_2	Green vegetables, oranges, apples, butter, lean meat	Liver extract, Brewer's yeast	Pellagra, anemia, bad digestion, bad skin	Good digestion, good nutrition, good skin	
B_3	Whole wheat, yeast			Growth	Little known
B_4	Wheat, lettuce, spinach, milk, yeast			Growth	Little known

Condensed from "The Vitamins," Journal Chem. Education, Sept., 1935.

A) are helpful in the dietaries of tubercular patients—evidence of the effect on the respiratory tract (Fig. 251).

This rat had no vitamin A. It weighed only 56 grams. Note the infected eye, rough fur, and lack of vigor.



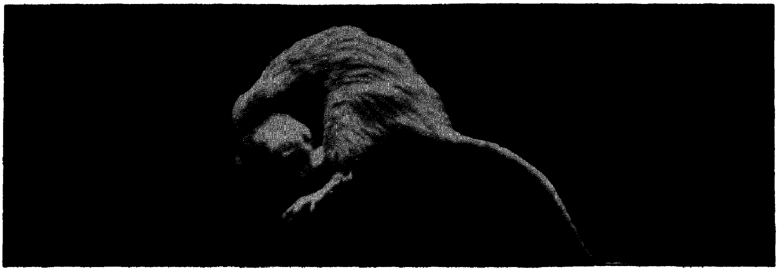
This one had plenty of vitamin A and weighed 123 grams. It has bright eyes and sleek fur and is vigorous.

Foods rich in vitamin A. Butter and cream—Whole milk—Cheese, made from whole milk—Eggs—Liver, all kinds—Cod-liver oil—Other fish-liver oils—Salmon, red—Green and yellow vegetables—Yellow fruits—Tomatoes—Olives.

FIG. 251.—Vitamin A for growth, and the prevention of certain infections. Rats from the same litter, 11 weeks old. (*Bureau of Home Economics, U.S. Dept. of Agr.*)

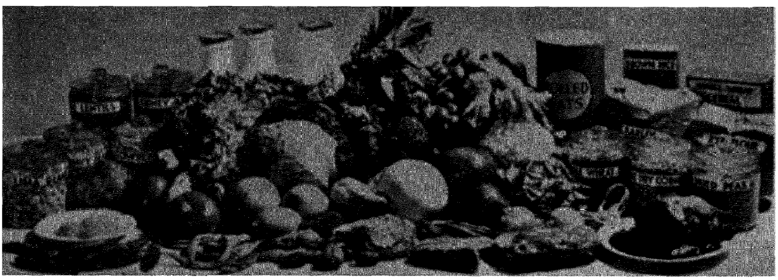
Vitamin A is fairly stable, but is partially destroyed by prolonged cooking at high temperatures in the presence of air. It can be stored in the body in rather large amounts and for long periods.

Vitamin B_1 aids appetite and digestion, maintains the integrity of the nerves, prevents beriberi, aids reproduction.



This rat did not have enough vitamin B. The lack of muscle control is called spastic paralysis.

The same rat 24 hours later, after receiving a food rich in vitamin B. Already it has recovered muscle control.



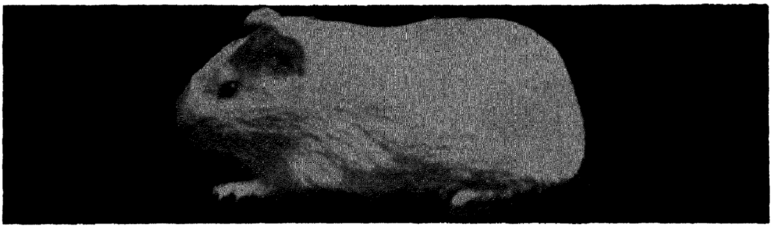
Good sources of Vitamin B. Milk, all forms—Fruits—Vegetables—Whole grains—Nuts—Beans, peas, and other legumes—Liver and other edible organs—Egg yolk—Lean pork—Oysters.

FIG. 252.—Vitamin B for good appetite and good muscle tone. Female rat, 24 weeks old. (*Bureau of Home Economics, U.S. Dept. of Agr.*)

Winter dietaries did not formerly contain much vitamin B or C. Fatigue, loss of appetite, rheumatism, and nervousness were common complaints late in winter. Spring tonics were popular. With

the coming of fresh fruits and vegetables the disorders cleared up —to the undeserved credit of the patent medicines and familiar old home remedies. Vitamin B_1 is not very stable to oxidation at high temperatures (Fig. 252).

This one had no vitamin C and developed scurvy. Note the rough fur and crouched position due to sore joints.



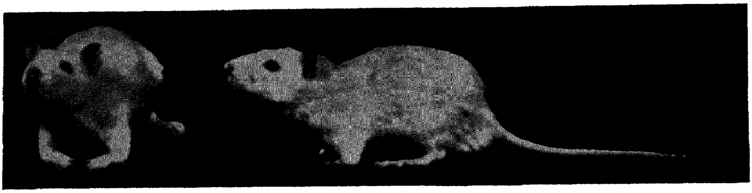
This one had plenty of vitamin C. It has sleek fur and is healthy and alert.

Good sources of vitamin C. Fresh fruits, especially citrus fruits—Tomatoes, fresh and canned—Fresh vegetables, especially cabbage—Sprouted legumes.

FIG. 253.—Vitamin C for healthy gums and teeth. Guinea pigs of the same age. (*Bureau of Home Economics, U.S. Dept. of Agr.*)

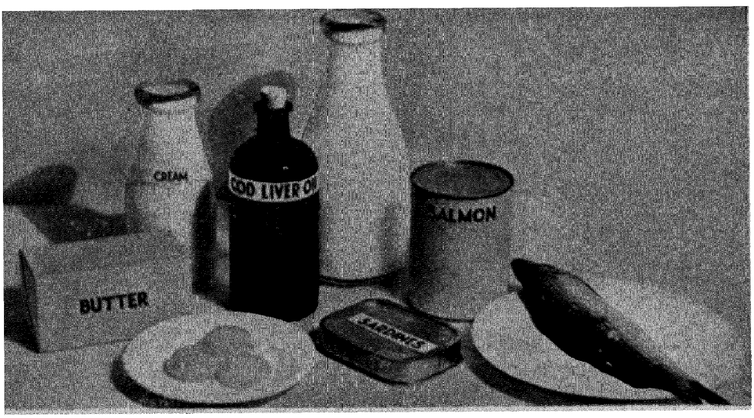
Vitamin C is a very interesting vitamin. It protects against scurvy, a disease in which the blood capillaries break down so that hemorrhages occur in skin, joints, limbs, and marrow. The mouth becomes sore to the extent that eating becomes painful.

Pains in the joints, fatigue, and swelling of limbs are common symptoms. Some authorities claim that much latent scurvy exists today (Fig. 253).



This rat had no vitamin D. Note the short body and bowlegs—typical signs of rickets.

This one had plenty of vitamin D. Its bones are strong and straight.



Foods that supply vitamin D. Fish-liver oils—Certain other fish oils—Oily fish, such as herring, sardines, salmon—Small amounts in Milk, Cream, Butter, Eggs.
FIG. 254.—Vitamin D for good bones and teeth. Rats from the same litter, 20 weeks old. (*Bureau of Home Economics, U.S. Dept. of Agr.*)

Vitamin C is also a great factor in the prevention of dental caries; it serves to maintain the integrity of the entire skeleton.

The modern use of orange, tomato, and other fruit juices has much more in its favor than most people are aware of. Apples, pears, and perhaps some other fruits lose their vitamin during storage, due to oxidation changes which take place within them.

Vitamin D is also called the antirachitic vitamin. It causes calcium and phosphorus to be deposited as bone and teeth. Compounds containing calcium and phosphorus are carried in the blood. As they reach certain cells they are converted into bone, providing vitamin D is also present. If there is a deficiency in any or all of these three factors, rickets result. The nervous system is affected first, then the muscles, skull, and sternum. Arm and leg bones are affected last. In very young infants, the soft spot on top of the head hardens late, legs are bowed, and other skeletal deformities develop (Fig. 254).

Vitamin D is interesting because it very definitely is made by photosynthesis, a process by which substances are built up with the aid of light. It has long been known that carbohydrates and perhaps some proteins are made in the chlorophyll of plants by photosynthesis. Solar energy is converted into chemical energy, which is stored in the newly made carbohydrates. Chlorophyll acts as the machinery, or catalyst, in the process. Nearly all of our food is made, directly or indirectly, by photosynthesis. Animals contain no chlorophyll, hence, can make no food. They are dependent upon plants or plant-eating animals. However, chlorophyll does not seem necessary in the photosynthesis of vitamin D, and vitamin D is the only substance produced in the human body by photosynthesis! A fat-like substance known as *ergosterol* is secreted by the skin; under the influence of ultra-violet light, ergosterol changes into a series of compounds, one of which is vitamin D (sometimes also called calciferol). Over-irradiation produces a harmful substance known as toxisterol.

Plant photosynthesis is a process in which carbon dioxide and water are combined to form sugar. Carbon dioxide enters through the stomata in leaves and green stems. Water is taken in through the roots. Under the influence of the chlorophyll and sunlight, molecules of formaldehyde are probably formed, which instantly combine with each other to form sugar. The chemical equation for photosynthesis is usually stated as:

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

As a result of this process, taking place in every chlorophyll-containing plant cell in the world, the carbon dioxide excreted in respiration of every animal is used, and oxygen, needed for respiration, is given off. Thus our carbon dioxide—oxygen balance is preserved. Sugar molecules may be changed into starch, protein, or fat in plants (as well as in animals), but these changes are not photosynthetic (except perhaps for a few proteins.)

Vitamin E has been shown necessary in animal reproduction. It has not yet been proven essential in human nutrition. Vitamin B_2 is supposed to maintain body well-being. It is thought by some authorities to aid in the prevention of pellagra.

The vitamin which was assigned the letter F did not seem to exist on subsequent investigation, so at present there is no vitamin F. It is known, however, that other vitamins exist. They are now being studied in biochemical laboratories the world over.

Vitamins are sometimes called dietary factors, for, with the exception of vitamin D they must be included with our food. Enzymes are definitely not included in our food—they are made either by certain glands or by cells of the alimentary tract itself. The third group of body catalysts—the hormones—are made in various glands of the body, and are concerned with body function. They are fascinating to study and when abnormal cause profound physiological changes.

HORMONES

Only a few endocrine secretions will be mentioned, by way of example.

Insulin is made by tiny groups of specialized cells (Islets of Langerhans) in the pancreas and is secreted into the blood. Its function is to start sugar metabolism. Diabetes mellitus is the pathological condition in which there is either a diminished supply or a total lack of insulin. We do not know why a pancreas will become lazy or totally lacking in insulin production. Fat people seem more susceptible than thin, and women more than men.

Until 1922 there was no hope for a diabetic, as insulin was unknown and the real nature of diabetes was not understood. Now, however, with the dramatic discovery of insulin by Banting

and Best, it can be given to diabetics so they can eat carbohydrate food more freely. If a pancreas is merely a little lazy, insulin may ease the strain on the pancreas, slowly enabling it to again function normally. Patients with a total or nearly total lack of insulin secretion must take insulin constantly. No cure for them is now known.

Thyroxine is secreted by the thyroid glands, situated one on either side of, and below, the Adam's Apple. This substance and adrenaline (secreted by suprarenal glands) stimulate energy metabolism. Iodine is an essential constituent of thyroxine and must be supplied by the diet. Goiter is the condition caused by an undernourished thyroid; however, there are at least seven types of thyroid abnormality, not all of which are produced by faulty nutrition.

When thyroxine is taken into the body, it takes effect slowly, but the stimulation lasts for weeks. Herein lies part of the danger of taking reducing medicines without a physician's prescription and supervision, for some of them contain thyroxine. It is possible to accumulate such a powerful overdose that the tissues will be uncontrollably consumed and death will result.

Adrenaline takes affect instantly and the stimulation acts for only a short time. When either thyroxine or adrenaline are taken there is an increase in tissue oxidation, with a greater carbon dioxide—oxygen exchange. The oxidation may exceed the fuel supply of the food, with the result that body fat is used.

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PROBLEMS

1. What is meant by an aromatic compound?
2. What is the benzine ring?
3. For what was Perkin famous?
4. What is the purpose of a laxative and how does it act?
5. Name and describe the classes of food?
6. What are hormones?
7. What is meant by the term vitamins?
8. Describe the process of starch digestion.
9. How is fat digested in the body?
10. What was Wöhler's contribution to science?
11. What is the difference between an organic and an inorganic compound?
12. Why is it difficult to digest half-cooked starch?
13. What is beri-beri?
14. What are the main constituents of face powders?
15. Explain the process of bread making. Why do we use yeast in the process?

TOPICS

Digestion.	Patent Medicines.	Synthetic Drugs.
Cathartics.	Dyes.	Perfumes.
Hormones.	Photosynthesis.	Vitamins.

EXPERIMENTS

1. Fermentation of Sugar. For this experiment use a 20% solution of sugar, or use one part of Karo to three of water. Add one yeast cake, which has been broken to bits. Set aside in a warm (about 75° to 80°F.) place for a day. Carbon dioxide gas is generated and alcohol is formed. The alcohol can be distilled off and recognized by its odor. It can be further identified by adding strong acetic acid and concentrated sulfuric acid to a little of it. A fruity odor results. This experiment not only demonstrates the changing of one organic compound into another, but it also illustrates the work of yeast.

2. Test for sugar.

To a few cubic centimeters of any sugar except sucrose add a little Benedict's reagent. Heat to boiling and note color. This test identifies sugars as a group. Cane sugar, however, does not respond. Karo, honey, or bananas may be used.

3. Test for starch.

Boil a very small pinch of starch in half a test tube of water. Let it cool, and when cold, add tincture of iodine. Blue indicates starch, violet indicates dextrin.

4. Test for protein.

There is no one test which will identify all proteins. Certain tests will identify certain organic groupings, which may or may not be present in protein. These groupings may also be present in non-protein material. The most universal test is the Biuret test.

To a little egg white, add concentrated sodium hydroxide and very dilute copper sulfate. Warm gently. A purple color indicates protein; a red-violet color indicates partially digested protein.

Test for Fat.

Place a piece of meat fat or other fat, on a piece of brown wrapping paper. Warm it in an oven. A translucent spot indicates fat.

5. Tests for Cosmetics. Beery, "Chemistry Applied to Home and Community" gives specific tests for cosmetic ingredients

6. Make up a list of perfumes and give their chemical names.

7. Make up a balanced diet for yourself for one day, consisting of 2500 calories.

8. Make a list of the vitamins and their uses.

9. Place a green plant in the dark for two days. Note the change in color.

10. Any college chemistry text will give instructions for making an organic dye. The advanced student may perform this experiment.

23

CLEANSING

"He is like fuller's sope."
Malachi

DIRT

DIRT CONSISTS of carbon and other particles which have been rubbed into the fiber of the cloth or have become fastened to the cloth by grease. Small bits of food may also cling to the fibers. Paint, dyestuffs, colored juices, and other materials may become attached to or absorbed by the fibers thus causing stains. The removal of dirt is comparatively simple. Stain removal may become rather complex, depending upon whether stains adhere to the fibers, are actually absorbed by them, or react with them. The primary problem is to dissolve the dirt or stain if possible. Water dissolves some substances readily, but will not dissolve others such as grease. Carbon will not dissolve in anything. Though warm or hot water will dissolve some substances which are insoluble in cold water, cold or hot water alone will not cleanse well.

Methods of Cleansing

There are five general methods for cleansing:

1. *Use of soap*	Dirt is emulsified and peptized.
2. *Solution*	Dirt is dissolved in some liquid.
3. *Absorption*	Dirt is absorbed by a solid, usually a powder.
4. *Chemical change*	Dirt which is insoluble in ordinary solvents is changed into a soluble substance, or is bleached, by a chemical reagent.
5. *Abrasion*	Brushing and scouring are examples.

USE OF SOAP. Dust and carbon particles are frequently held on textiles by oil or grease. Soap removes the oil, setting free the dirt particles which may then be removed by rubbing or agitation. The exact manner in which soap acts is obscure. In some cases, soap reacts with water to form a weak alkaline solution which

removes dirt by emulsification. However, soap does not always form sufficient alkali for emulsification. Frequently, too, grease is not present.

Emulsification. Emulsification means the surrounding of droplets of fat or oil with a film of soap or some other substance. The film prevents the droplets from running together again. For instance, when oil and water are shaken together and allowed to stand, the oil droplets, which have been formed during the shaking, coalesce into a layer on top of the water. When soap solution (alkalies may also be used) is added and the mixture is again shaken, the oil does not form a layer but remains dispersed throughout the water.

Surface Tension. Soap lowers the surface tension of water, thus permitting it to penetrate into tiny spaces that pure water will not wet. Surface tension is caused by the surface molecules sticking together. Mercury has a high surface tension; it forms into little globules when spilled on a desk. The surface tension of water is not as great as that of mercury, so water drops are flattened and may even spread out a little on the desk. Kerosene has a low surface tension and when dropped on wood or water spreads out as a thin film, even penetrating spaces which are inaccessible to water or mercury. (This explains why kerosene is used to loosen rusted bolts.)

Peptization. Soap also peptizes or splits the dirt particles into pieces having colloidal dimensions. Colloidal dirt particles adsorb soap molecules on their surfaces. The soap being soluble in water, carries the dirt away with it.

Summary of Soap Cleansing. Cleansing by soap, therefore, is threefold in its action: it emulsifies the oil, it permits the water to penetrate, and it peptizes the dirt. In the absence of oil, the other two processes serve to remove the dirt.

Soap. Soap is a salt of sodium or potassium hydroxide and a fatty acid and is one of the most important of the salts that have an alkaline reaction in water. If, for example, oleic acid and sodium hydroxide are mixed, a soap is formed called *sodium oleate*. Other fatty acids are *stearic* and *palmitic*. In actual practice the fatty acids are not used because of their cost. Instead the

fats, glyceryl palmitate, glyceryl stearate, and glyceryl oleate are used. The equation for the reaction follows:

$$\underset{\text{glyceryl palmitate}}{C_3H_5(C_{15}H_{31}COO)_3} + \underset{\substack{\text{sodium}\\\text{hydroxide}}}{3NaOH} \rightarrow \underset{\text{soap}}{3Na(C_{15}H_{31}COO)} + \underset{\text{glycerol}}{C_3H_5(OH)_3}$$

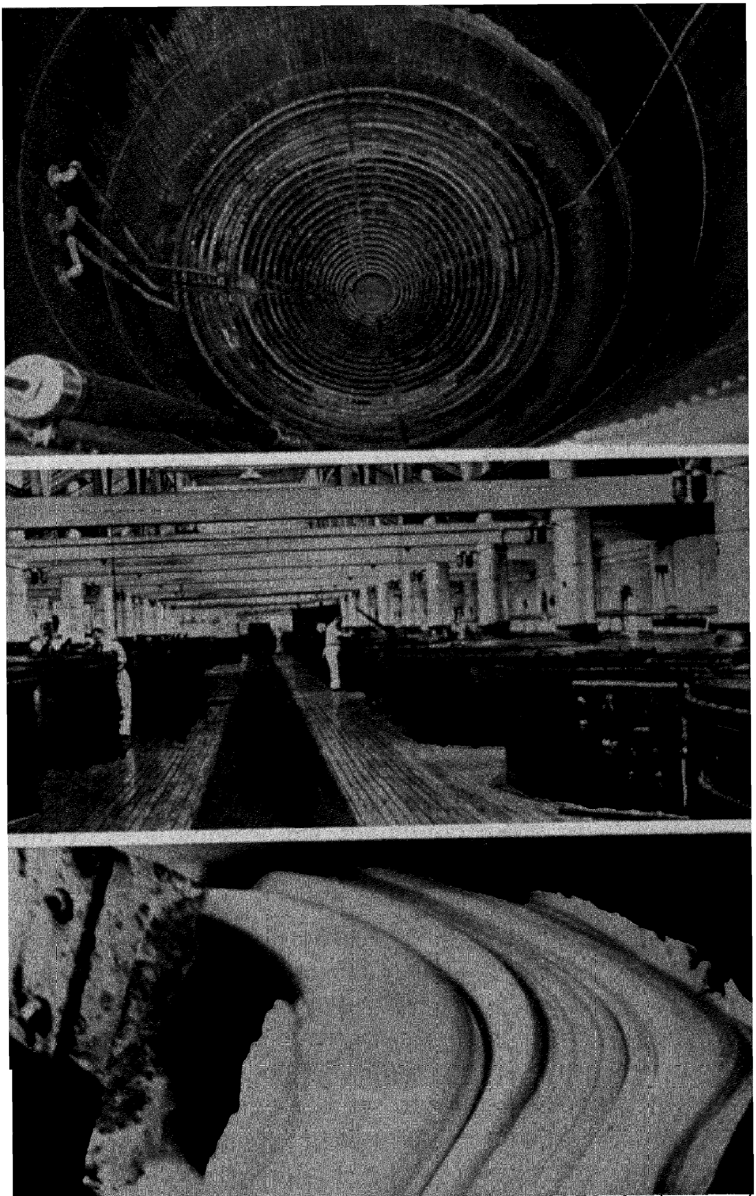
If potassium hydroxide is substituted for sodium hydroxide, we have liquid soap. Glycerol is the chemical name for glycerin and it is a very valuable by-product of the soap industry. It is used in the manufacture of nitroglycerin and in many other chemical processes.

A History of Soap. Soap has been used for many centuries, indeed it is mentioned in the Old Testament.

"For though thou wash thee with nitre and take thee much sope yet thine iniquity is marked before me" Jeremiah, 2–22. Just what this soap was it is difficult to determine, yet it is probable that it was made by mixing the tallow of sheep and cattle with wood ashes, which produced a type of soap mixed with residual fat and ashes. It is not known that the Egyptians used soap so that the statement that "Cleopatra's beauty was preserved by palm and olive oils" is open to question. It appears that the use of soap was almost unknown in the Middle Ages, hence the references to the people of that time as the "Great Unwashed."

In colonial times, the women made soap from fat and wood ashes. After about 1820, soap began to be a commercial product and its quality has been improved greatly during the past century. By the development of the process of the hydrogenation of liquid fats, the oils such as fish oil and cotton-seed oil have become important constituents of soap.

Varieties of Soap. Laundry soap is made from tallow to which may be added rosin for greater lathering, or naphtha for greater solvent action. If free alkali is present it will cause the hands to become rough and tender and will weaken textiles. The use of such soaps is not economical, although they may sell for a trifle less than neutral soap. Scouring soaps contain some abrasive such as marble dust, pumice, or sand. Toilet soaps are made from tallow and cocoanut oil, or from palm, cocoanut, and



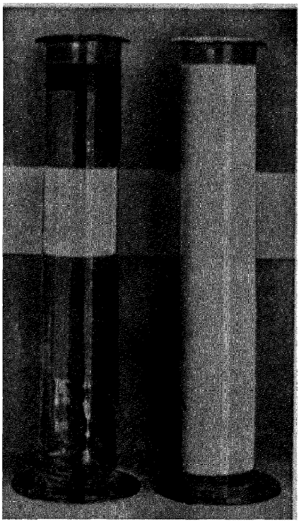
(a)

(b)

(c)

FIG. 255.—The manufacture of soap. (a) A soap kettle. (b) The kettle room. (c) A river of soap. (*Courtesy Proctor and Gamble.*)

olive oils (Fig. 255). They should be neutral. Perfumes and dyes are often added. Floating soaps contain air. Hardwater soaps contain borax or sodium carbonate, since both of these materials soften water. It is important to emphasize that no secret formula exists for any type of soap. Practically all soaps have the same fundamental chemical composition. (Exceptions are the compounds of sulfonic acid with hydrocarbons.)



A B

FIG. 256.—Emulsions. A. In this jar, oil and water have been shaken together. The oil will soon separate. B. In this jar some soap has been added to the mixture of oil and water. As a result the emulsion becomes more permanent. (*From McPherson and Henderson's, "Chemistry for Today," Ginn and Co.*)

The soap molecule, as is evident from the formula, consists of a very long chain of atoms. It appears that one end of the chain is soluble in water, while the other end is soluble in oils. Because of this property, the soap acts as an emulsifying agent to unite oil and water. Other examples of emulsification are: whole milk, in which the fat and water are held together by casein; mayonnaise, where egg unites vinegar and salad oil (Fig. 256).

Numerous chemicals have an alkaline reaction and a cleansing action similar to soap. These include ammonia, lye, washing soda, sodium silicate, and trisodium phosphate. The last three are occasionally added to soap and are the principal constituents of most washing powders such as "Old Dutch Cleanser."

SOLUTION OF DIRT. Spots of car grease, butter, and other fats, which are not always cleaned readily with hot soap suds, may be dissolved by using typical fat solvents. In general, fats and oils may be removed by using ether, gasoline, carbon tetrachloride, or chloroform. Ether evaporates so rapidly that dirt rings may remain on the textile. These rings may be avoided by gently rubbing a clean, ether-soaked rag with a circular motion from

the outside of the spot towards its center. It must be emphasized that ether, alcohol, gasoline, and benzine are inflammable and *must not be used near a flame.* Carbon tetrachloride and chloroform are not inflammable and are safe to use. Carbon tetrachloride is commonly sold under the name of "Carbona."

Most ink, fruit, coffee, and other stains can be removed by washing them promptly before they have a chance to set. For instance, ordinary fountain pen ink can be removed while fresh by washing with plain water. After it dries, insoluble iron compounds are formed, which makes chemical removal necessary.

ABSORPTION. Grease stains may be removed from suede or cloth garments by using a powdered absorbent. French chalk (a very pure, finely pulverized magnesium silicate), magnesium oxide, Fuller's earth, and talcum powder are commonly used. Any one of them is placed upon the grease spot and left for an hour or two. It is then brushed off. Fresh applications of the powder are used on stubborn spots. Grease and paraffin may also be removed by pressing the material between two clean blotters with a warm (not hot) iron.

CHEMICAL REMOVAL. Many stains are insoluble in all of the common solvents. They must be bleached or changed into soluble compounds. Great care must be exercised in using any chemical reagent, as it may permanently injure the fabric. It is advisable to try the reagent on an inconspicuous part of the garment first to see that it does not react either with the fabric or its color. It is also advisable to determine whether the textile is cotton, linen, wool, or silk. Acids attack cotton; alkalies may injure cotton and will dissolve wool and silk.

ABRASION. Except for removing dust and mud we seldom brush or scour textiles. Abrasion is used on wood and metals. Steel wool may be used on pans and wood, but it scratches. Whiting and jeweler's rouge are used on gold, silver, and highly polished surfaces. A soft paste may be made by mixing the whiting or rouge with either ammonia or alcohol.

DRY CLEANING. Dry cleaning processes make use of gasoline, benzine, carbon tetrachloride, or ethylene chloride. The last two are most common. These dissolve oils and greases, thus setting

free the dirt particles which are then removed by mechanical agitation.

STAIN REMOVAL CHART. The following chart indicates the materials used for removing some common stains. For detailed instructions as to the procedure to follow in each case, and for the removal of additional stains, the references may be consulted. The Government Bulletin is particularly helpful.

1. *Blood*	Cold or lukewarm water; then sodium hypochlorite or ammonia or peroxide of hydrogen.
2. *Chewing gum*	Carbon tetrachloride and water alternately, or egg white followed by water.
3. *Fruit, tea, coffee, grass*	Water, then soap and ammonia, for cotton. For white wool use water, then permanganate (see note), then peroxide. For colored wool use water, then peroxide or alcoholic soap solution.
4. *Ink, iron rust, mildew*	Lemon juice and steam, alternately, or lemon juice, salt and sun, or soap and water, or sour milk.
5. *India ink*	Chloroform.
6. *Iodine*	Alcohol, or hypo, or potassium iodide solution.
7. *Paint*	Ether, or carbon tetrachloride, or turpentine.
8. *Scorch*	Peroxide (see Govt. Bull.).
9. *Tar*	Benzine or ether.
10. *Wax*	Alcohol, or press between blotters.

Note. To make permanganate solution, dissolve 1 teaspoonful of potassium permanganate crystals in a pint of water. Apply a drop or two, and allow it to remain five minutes. Remove the resulting brown stain from wool with hydrogen peroxide (to which has been added a few drops of some acid). From silk, cotton, or linen, remove the stain with saturated oxalic acid or lemon juice. Rinse well in every case.

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PROBLEMS

1. How is soap made?
2. Explain the cleansing action of soap.
3. State three general methods for stain removal.

TOPICS

History of soap making.
How your grandmother made soap.
Borax Mining.
Modern Soap Production.

EXPERIMENTS

1. Remove a grease spot by absorption.

2. Remove a grease spot with carbon tetrachloride.

3. Remove other typical stains, following the directions for each case as given in any of the first three references cited.

4. Surface tension. (*a*) Bend one end of a clean wire into a ring with a diameter of about one inch. Tie a small loop of silk thread to the ring. Dip the ring into a soap solution to which has been added a little glycerin. Hold the resulting film up to the light, and notice the motion of the liquid particles. Touch the inside of the loop with a hot wire. The loop assumes a circular shape, which shows that there is equal surface tension on all sides.

5. To identify free alkali in soap, dissolve it in absolute alcohol. Add alcoholic phenolphthalein. A red color indicates free alkali.

24

TRUE AND APPARENT SOLUTIONS

"It is the part of scientific men to lift the veil from the mysteries of Nature."
Hume

As we drop a lump of sugar into a cup of tea, we notice that in a very short time the sugar has disappeared, and we find that the tea tastes sweet. We all know that sugar dissolves more rapidly in hot tea than in tea that is merely lukewarm.

For centuries man has made solutions, but, as yet we know very little about the process. For example, if we try to dissolve a lump of marble, an object resembling sugar, we find that it is impossible to make a water solution of the rock. Why do salt and sugar dissolve in water while marble does not? Scientists believe that water molecules moving about as clusters in the liquid bombard the sugar and break the lumps apart. For some reason the marble does not break apart under the bombardment. Perhaps marble molecules cling too firmly to each other.

The process of solution presents so many curious differences, that a simple explanation is impossible. Sugar dissolves in water, but not in ether; butter dissolves in ether, but not in water; we may dissolve 13 grams of potassium nitrate in 100 grams of water at 0°C., and 246 grams at 100°C.; we may dissolve 35.6 grams of salt at 0°C., and 39.8 grams at 100°C. Alcohol dissolves in water in any proportion and the temperature rises; ammonium chloride dissolves freely in water, but the temperature falls. One liter (about one quart) of water dissolves 1298 liters of ammonia gas at 0°C. and only 710 liters at 20°C. (Fig. 257).

Scientists are not agreed as to whether solution is purely mechanical or a type of chemical process. Sugar dissolved in water acts like a gas by exerting pressure. This process would appear to be mechanical. On the other hand, we often get curious

color changes when materials go into solution. If we dissolve anhydrous copper sulfate (which is a gray material) in water, the solution is blue. When the salt is crystallized out of solution, the substance retains some water of crystallization and the crystals are blue (blue vitriol). Some substances like salt water conduct

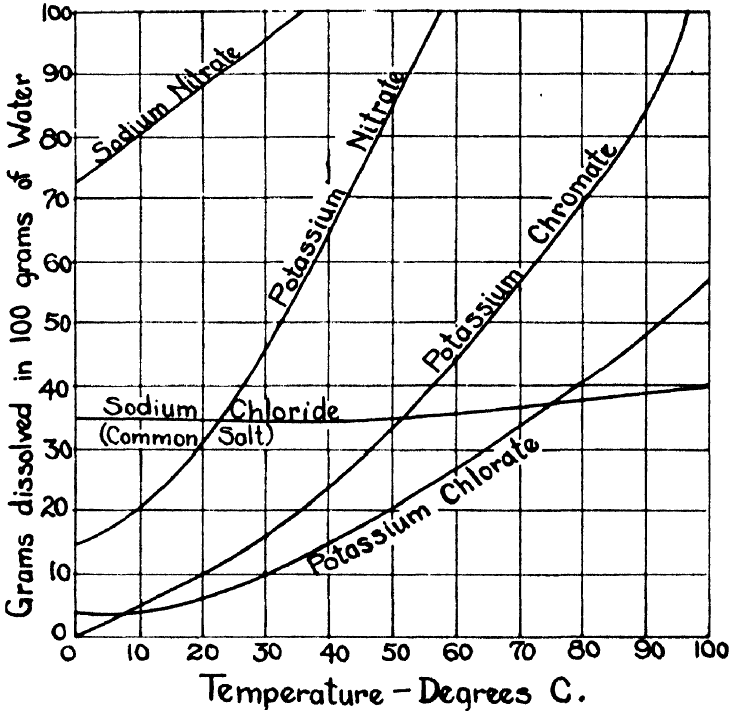

FIG. 257.—Solubility-temperature graph. To use the graph, it will be noticed that at 20°C., 30 grams of potassium nitrate will dissolve in 100 grams of water. (*Wendt and Smith.*)

electricity while others like sugar solution do not. Probably the best idea is that solutions stand midway between chemical compounds and simple mixtures or suspensions. In support of solutions as chemical compounds there are some very common types of solutions which appear to be accompanied by chemical reactions. When ammonia gas is dissolved in water, there is every evidence that it does react with water forming the base,—ammonium hydroxide. However, no one has ever isolated am-

monium hydroxide as a separate substance. Similarly, carbon dioxide gas seems to combine with water to form carbonic acid which gives the acidity to "soda water." If we pour concentrated sulfuric acid into water (never add water to concentrated acid) the solution becomes very hot. In these cases, we do know that chemical changes have taken place.

SOME TERMS USED IN SOLUTION. In discussing solution we use the term *solvent* or *dispersion medium* to mean the liquid, gas, or solid in which the substance is dissolved. The dissolved substance is called the *solute.* In the case of the solution of gases in gases, liquids in liquids, and solids in solids, the predominating substance is the solvent. Gases will mix in any proportion. We have, for example, the mixture of the gases in the air. In this case we might regard the nitrogen as the solvent. Some liquids such as alcohol and water are miscible in all proportions. If the alcohol is less than half the mixture, it is the solute. If its proportion exceeds the water, it is the solvent. If we clamp a piece of gold to a bar of lead, the gold will penetrate into the lead. We regard the lead as the solvent. The gas, hydrogen, will dissolve in the metal platinum.

A concentrated solution is one that contains a relatively large amount of solute. At 20°C., 100 grams of water dissolve 109 grams of sodium hydroxide. If we dissolve only about 20 grams in 100 grams of water, we have a *dilute* solution; 90 grams would form a *concentrated* solution; 109 grams, a *saturated* solution. In some cases, we can even form *supersaturated* solutions. When a hot saturated solution is allowed to cool slowly, it some times happens that the excess solute does not settle out of solution. Hence, the cool solution contains more solute than is usually held at that temperature. This is a supersaturated solution.

One commercial application of such a solution is a new type of self-heating hot water bottle. A solution of hypo (sodium thiosulfate) is supersaturated and allowed to cool in the metal container used as the hot water bottle. If the container is shaken, some of the salt precipitates and heat is liberated.

PROPERTIES OF SOLUTIONS. Substances dissolved in water modify the properties of the water. Every housewife is familiar

with the use of salt in water for cooking purposes. Salt has the property of raising the boiling point several degrees, so that the starch cells and muscle tissues break down more rapidly, thus hastening the cooking.

A mixture of salt and ice melts at a lower temperature than ice alone. People scatter salt over icy pavements to speed up the melting of the ice. In the winter we use materials in our automobile radiators to prevent the water freezing. Some of the substances used are glycerin, alcohol, ethylene glycol. Such solutions have a lower freezing point than pure water. A desirable anti-freeze should not injure the radiator, should flow freely in cold weather and should not evaporate to any extent. Alcohol, while the cheapest anti-freeze, evaporates rapidly. There are several new organic substances which are very satisfactory. Most of them are sold under trade names.

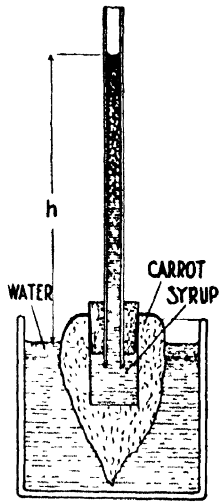

Fig. 258.—Owing to osmosis, water has passed through the carrot into the sugar solution. The height (h) measures the osmotic pressure. (*Foley.*)

OSMOSIS

A very interesting and to some extent mysterious effect produced by solutions is *osmosis*. If we fill and seal a sausage casing with concentrated sugar solution and place it in a beaker of water, we shall find that after a few hours the sausage casing will swell and even burst because of the water which has entered. During this time very little sugar has passed into the water outside. The housewife soaks dried fruits, such as prunes, in water to restore the water lost in drying. *Osmosis might be defined as the diffusion of solvent particles through a semi-permeable membrane.* An experiment within the reach of every science class is the osmosis of a carrot as shown in Fig. 258. The carrot is hollowed and the cavity filled with syrup. A cork and a glass tube are inserted. If the carrot is placed in a dish of water, the water will slowly diffuse through the shell of the carrot and pass into the syrup. As the volume of the

syrup increases, the solution rises in the glass tube. *The height of the liquid in the tube is a measure of the osmotic pressure.* Both the sugar solution and the water tend to reach the same degree of saturation.

Osmosis is one of the most important factors in the behavior of living matter. Air passes through the lungs into the blood, and carbon dioxide passes out of the blood into the lungs by osmotic pressure. Soil water passes through root hairs into the plant, thus carrying dissolved minerals and other food materials to the plant. Should salt be thrown on the ground, or should too much fertilizer be applied, the concentration of the soil water would become greater than that of the plant protoplasm, thereby

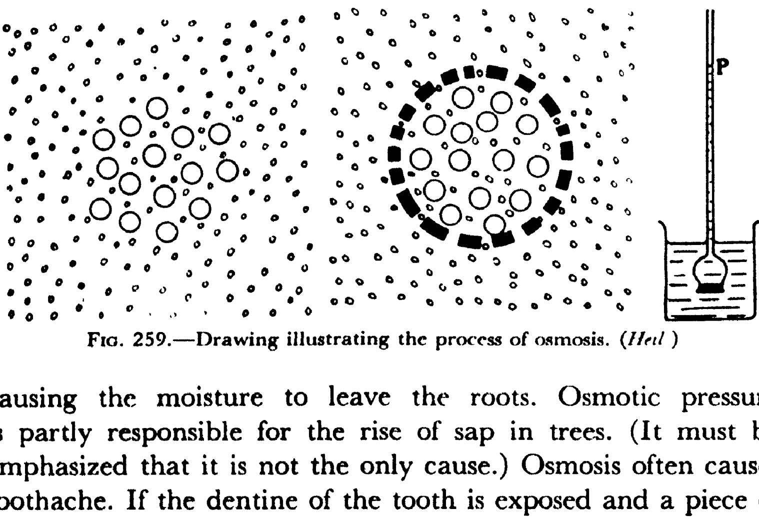

Fig. 259.—Drawing illustrating the process of osmosis. (*Heil*)

causing the moisture to leave the roots. Osmotic pressure is partly responsible for the rise of sap in trees. (It must be emphasized that it is not the only cause.) Osmosis often causes toothache. If the dentine of the tooth is exposed and a piece of candy is placed in the mouth, the saturated syrup in the mouth produces an effect on the nerve by osmotic pressure through the porous dentine.

Both the rise of the boiling point and the osmosis of solutions are best explained by the vapor pressure of water as compared with the vapor pressure of the solution. It appears that a substance such as salt when dissolved in water tends to hinder the water molecules from escaping from the liquid. If pure water and solution of some substance in water are placed on opposite sides

of a porous membrane, the water molecules in contact with the membrane on the water side have more freedom of motion and can diffuse freely through the wall. On the other side, the water molecules are bound to the molecules of the solute so that neither water nor solute pass freely through the porous wall because these solvent-solute clusters reduce the evaporation tendency of the water. (A less satisfactory explanation states that the pores of the wall are large enough for the water molecules to pass in one direction, but too small for the passage of the solution clusters in the opposite direction.) Consequently, the water will pass through until the pressure set up by the height of the solution prevents further passage by equalizing the tendency for water diffusion. Figure 259 illustrates the osmotic pressure through a membrane separating the solution and a solvent.

COLLOIDS

The individual particles of the solute in a solution are too small to be seen by means of any device now known. They probably consist of single atoms or molecules and can pass through animal or vegetable membranes and filter paper. There is a different class of substances, very common in daily life, which has very peculiar properties. These substances are tiny aggregations of atoms and molecules which, while invisible to the eye even with the aid of a microscope, are very large compared to atoms. They are called *colloids.* We can taste and smell some of these colloids even though we cannot see them. Every hay fever sufferer is aware of the tiny particles of plant pollen which irritate the nose and throat. We are familiar with the smell of new mown hay and the scent of flowers. Each of these materials is probably of colloidal size.

Colloids may be defined as particles which will pass through animal membranes and parchment paper. They cannot be filtered by the usual processes. Such substances may be classified into 8 groups as follows:

1. *Solid in solid*	Gold in glass (gold ruby glass).
	Selenium in glass (red glass).

2. *Solid in liquid*	Gold in water.
	Sulfur in water.
	Sodium chloride in alcohol.
3. *Solid in gas*	Blue tobacco smoke.
	Invisible dust in the air.
4. *Liquid in solid*	Water in calcium carbonate (pearl)
5. *Liquid in liquid*	Emulsions (mayonnaise).
	Gelatins in water.
	Jellies.
6. *Liquid in gas*	Fog and cloud in air.
7. *Gas in solid*	Sea foam candy.
	Floating soap.
	Gray hair.
8. *Gas in liquid*	Soap suds.
	Whipped cream.
	Foams.

Almost all of the processes of living tissue are concerned with colloidal dispersions. The cells, including both protoplasm and cell walls, are colloidal. The physiologist who studies such body processes as nerve action, digestion, circulation, and secretion, is concerned with colloidal dispersions.

The chemistry of colloids concerns such varied subjects as blue eyes, photographic film, cheese, salad dressing, tanning, cement, rubber, glass, paint, varnish, foam, pottery, blue of lakes and blue of the sky, colors of feathers and colors of paints, baking of bread, dyeing, water purification. Truly colloids are a part of our daily life.

Although we cannot see colloids directly, if the source of light is properly adjusted, we may see the diffraction pattern due to the light scattered by these tiny objects. We see clouds (colloidal water) and we notice the dust particles dancing in a beam of sunlight in a darkened room. *The ultra-microscope*, invented in 1908, utilizes the principle of the dancing particles in the light to make the position and motion of colloidal particles visible. A strong horizontal beam of light (Fig. 260) is focused, by means of a system of lenses, at a point in the glass cell on the microscope stage. The particles in the colloidal solution in the cell scatter the light, thus producing a diffraction pattern. The light does not enter the microscope directly so that only rays scattered sidewise

are seen. We do not actually see the detail of the particle, but a diffraction pattern around it.

The ultra-microscope makes particles visible which are as large as 10 millimicrons* (one hundred-thousandth of a milli-

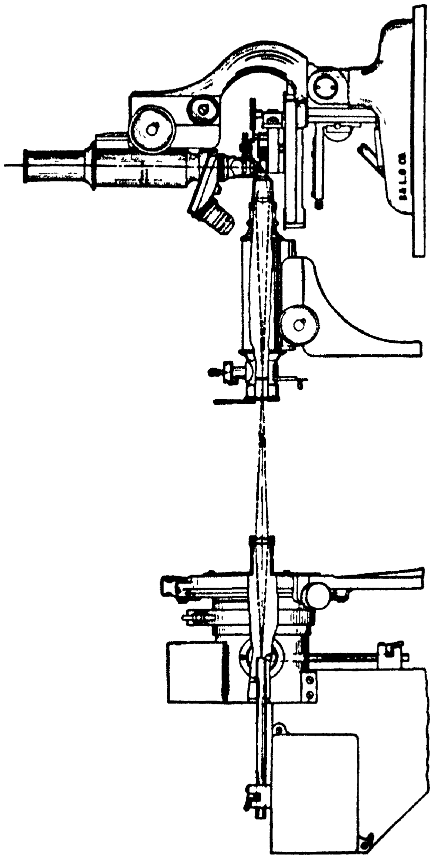

Fig. 260.—Diagram of an ultra-microscope. (*Courtesy of Bausch and Lomb Optical Co.*)

meter). Since molecules are much smaller than this they cannot be seen in an ultra-microscope. It may be that some of the very large molecules of proteins can be viewed by the ultra-microscope.

Preparation of Colloids. Colloids may be prepared by grinding, by peptization in water, by emulsification, and by

* One micron is 1/1000 mm., one milli-micron is 1/1,000,000 mm.

electrolysis. The colloid mill is a device used to grind materials so fine that they are colloidal in size. Another dispersion method is the arcing of metals in water. If two electrodes of gold, silver, or platinum are connected to a source of electricity and the tips placed nearly in contact under water, an arc will pass and small particles of the metals will scatter into the water forming a colloidal dispersion. When an oil and a liquid such as water or vinegar are mixed in the presence of an emulsifying agent such as egg or milk casein, an emulsion is formed which is partly colloidal. In the chemistry laboratory, one may form a colloidal mixture very simply by pouring ferric chloride into boiling water. We may form some colloids by simply mixing substances with water. If we mix glue or gelatin with hot water, a colloidal dispersion is formed. We are all familiar with the dessert "Jello" which is colloidal in nature.

Because of their size, colloidal particles have interesting properties. They have astonishing powers of absorption because of their great surface area. The gels contain large amounts of water (gelatin dessert contains twenty times as much water as gelatin); foam contains many times more gas than the foaming agent (try experiment 6 at the end of the Chapter). It has been discovered that many colloidal particles are electrically charged. Perhaps this may explain the bactericidal action of the colloidal silver dispersions "Argyrol" and "Neosilvol" which are used for diseases of the nose and throat. It is possible that the bacteria may be killed by the charge of electricity delivered by the colloidal silver? The continued use of silver causes a condition called argyria, which is characterized by a bluish discoloration of the skin and mucous membranes.

An interesting application has been made of the fact that colloidal clays have a negative charge. Wet brick clay has a decided tendency to stick to metallic surfaces. This formerly necessitated special lubrication of brick-cutting wires. It was found, however, that by making the cutting wires the negative electrode (cathode) and the wet clay the positive electrode (anode) of a direct current system, the clay is repelled from the wire and cutting can proceed freely.

Perhaps the most important application of the electrical charges on colloidal particles is the *Cottrell process* for the removal of smoke from the gases of factory stacks. Two highly charged electrodes are placed in the chimney (Fig. 261) and as the smoke passes between the electrodes the small particles are pulled from the flue and drop as sediment. Not only does this process remove

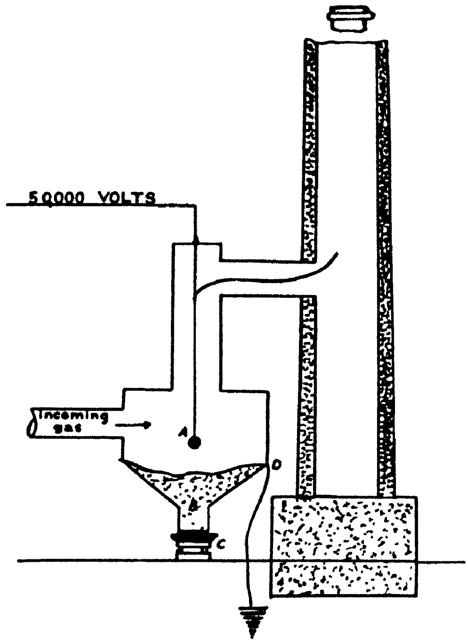

FIG. 261.—The Cottrell process. (*From Gray, Sandifur and Hanna's, "Fundamentals of Chemistry." Publishers, Houghton Mifflin Co.*)

the nuisance of smoke, but it makes possible the recovery of valuable materials such as metals and salts.

SUSPENSIONS

The energy of motion, exhibited by colloids, known as the Brownian movement, is sufficient to overcome the force of gravity, with the result that colloids do not settle out on standing. Larger particles do settle out. If the state of division is small (but still larger than colloidal in size), matter in suspension

may not settle readily. In certain parts of the country, forest fires rage for days at a time. The fine smoke particles travel hundreds of miles obscuring the sun and causing brilliant sunsets. At the time of the volcanic explosion on Krakatoa, fine dust travelled around the world. The dust storms in central United States and China deposited sediment many hundreds of miles from the source of the dust.

The following table compares the characteristics of solutions, colloids, and suspensions.

Solutions	*Colloids*	*Suspensions*
Atoms or small molecules.	Small aggregates of atoms and molecules	Very large clusters of molecules.
Invisible.	Ultra-microscope.	Visible.
Pass through filter paper.	Pass through filter paper.	Will not pass through filter paper.
Pass through membrane.	Will pass through some membranes.	Will not pass through membranes.
Do not settle out.	Do not settle out.	Settle out.

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PROBLEMS

1. What is meant by a solution?
2. How does a solution differ from a colloidal suspension?
3. Why is whipped cream a colloid rather than a solution or a suspension of air in cream?
4. What evidence is there that solution is a chemical process?
5. What is a solvent? a solute? a dispersion medium?
6. Can we dissolve a solid in a gas?
7. Can we dissolve a liquid in a gas?
8. What is meant by osmosis?
9. What are some examples of osmosis in nature?
10. Can we see a colloid? Explain.

11. The biologist finds that blood corpuscles burst when placed in distilled water. Can you explain?
12. Why are salts used as laxatives?
13. How does soap-suds differ from liquid soap?

TOPICS

Gas Masks.	Foamite Fire Extinguishers.	Dust Storms.
The Brownian Motion.	Neo-silvol as an Antiseptic.	Deliquescence.

EXPERIMENTS

1. Prepare a supersaturated solution of sodium acetate by dissolving 275 grams of it in 100 cc of water. Let it cool slowly. When it is cool, drop a crystal into the flask. Watch the growth of crystals and notice the evolution of heat (Owing to the expense of chemicals have one student perform this for the class.)

2. Dissolve 20 grams of salt and 2 grams of gelatin or albumin (5 cc. of egg white will do) in 100 cc. of water. Place it in a thistle tube while you hold your finger against the small end of the tube. Tie a piece of parchment paper or animal membrane over the large end. Invert the tube and suspend it in a beaker of distilled water. See that the level of the solution is even with the water in the beaker. Observe and explain what happens in a few hours.

Perform these tests 25 to 48 hours after the experiment has started. Salt molecules may be identified by a white precipitate when silver nitrate (do not add nitric acid this time) is added to a few cc. of water from the beaker. Were the salt molecules small enough to pass through the membrane? Gelatin or albumen is identified by adding nitric acid to a few cc. of beaker water; on warming, a yellow color results, which turns orange when ammonium hydroxide is added in excess. Were these molecules small enough to pass through?

3. Into 100 cc. of *boiling* water, pour 5 cc. of ferric chloride solution. Result?

4. To prepare a gel, dissolve 5 grams of gelatin or 3 grams of agar in 100 cc. of boiling water. Let it cool.

5. Colloidal flower garden. Dilute some concentrated sodium silicate (or use undiluted water glass) with an equal volume of water, in a beaker. Drop small lumps or crystals of ferric chloride, copper sulfate, cobalt chloride, nickel nitrate, manganese sulfate, chrome alum, and other very soluble colored salts into the beaker. Let it stand for several hours, noting the results from time to time.

6. Add 3 grams of licorice powder to 50 cc. of 10% sodium carbonate solution. Pour this rapidly into a tall cylinder containing 50 cc. of 10% aluminum sulfate.

25
WATER AND ITS APPLICATION TO DAILY LIFE

"Pure water is the best of gifts that man to man can bring."

BECAUSE OF the fact that water is such a part of our daily lives, we rarely think of it as an interesting substance. Actually, water is one of the most unique substances in the universe. It may exist as a vapor, liquid, or solid under ordinary conditions. It acts as no other substance in that it contracts until 4°C. (39.2°F.) is reached and then it expands with further decrease of temperature. This explains why ice floats on water. (One cubic foot of water weighs 62.4 pounds and one cubic of ice weighs only 56 pounds.) About 1/9 of a cake of ice is above the surface of water.

The amount of water on earth is enormous, over 3/4 of the globe being covered by oceans with an average depth of over two miles. In addition, the solid crust itself contains an amazing quantity of water. Water penetrates nearly everything, even granite having about one pint of water per cubic foot.

Water is composed of hydrogen and oxygen. As we ignite a jet of hydrogen and hold the flame under a cool surface, we see drops of water forming. If a current of electricity is passed through acidulated water, the water molecules are separated into hydrogen and oxygen (Fig. 262). (Acidulated water must be used since pure water is practically a nonconductor of electricity.) In terms of the theory of dissociation, the process is somewhat as follows: as hydrochloric acid is mixed with the water, some of the acid molecules separate into H^+ ions and Cl^- ions. The hydrogen ions move to the cathode and accumulate as hydrogen gas. The chlorine ions move to the positive electrode and, at that point, combine with water to liberate oxygen with the formation of hydrochloric acid. In consequence, the amount of hydrochloric acid remains unchanged as the water is separated into its constituents.

Since water is such a common substance we use it in many ways as a standard. One cubic centimeter of pure water at 4°C. is said to weigh one gram. We use it as a fixed point for thermometer scales, as a measure of specific heat, and of the calorie. In chemistry and in daily life, it is a solvent for many substances.

The origin of water on the earth is associated with the origin of the solar system. Most scientists believe that the elementary gases, hydrogen and oxygen, combined to form steam at the high temperature of the earth in the astral condition (see p. 92). (It may be that water does not exist on any other planet. There is, at present, some evidence that Mars contains very little if any water.) As the earth cooled, the water vapor slowly condensed to form water which filled the depressions in the earth's crust thus forming oceans. As we have stated (see p. 78), the calculation of the amount of salt in the seas leads to the result that at least 100 million years have elapsed since the first water was deposited in the oceans.

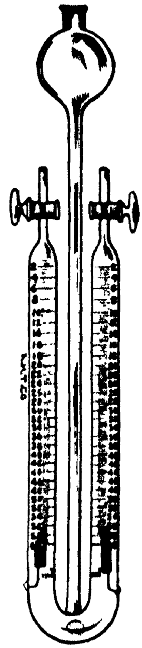

FIG. 262.—Hoffman apparatus for the electrolysis of water. (*Hackh, "Chemical Dictionary."*)

All plants and animals must have water to live. About 4/5 of the weight of animal tissue is water; while some plants are as much as 95% water. All plants take in water and lose many tons of water in a single year. This water rises from the roots as sap.

BUOYANCY

In Chapter 11, the subject of buoyancy was discussed and the principle was applied to balloons and dirigibles. The principle was stated by Archimedes about 240 B.C. An interesting legend tells of the circumstances which led to the discovery of the principle. It seems that Hiero, the tyrant of Syracuse, had commissioned a goldsmith to fashion a gold crown. After receiving it, Hiero became suspicious that considerable silver had been used. He asked Archimedes if one could detect the presence of silver in

the gold crown. Archimedes hit upon the answer by noticing that, while submerged in the bath, his body displaced an equal volume of water. He also recognized the fact that the force buoying up his body was the weight of the water displaced. He solved the problem by weighing the gold crown and an equal weight of pure gold, first in air and then when submerged in water. Were the crown alloyed with silver, the apparent loss of weight should be greater than for the gold bar. We may illustrate this principle by an example. Let us suppose that a pure gold crown weighs 20 pounds and has a specific gravity of 19. When immersed in water the crown would apparently weigh only 19 pounds. However, if the crown was an alloy of gold and silver, having a specific gravity of 13, then the apparent loss of weight would be nearly 2 pounds. Thus an adulteration could be easily detected without destroying the crown.

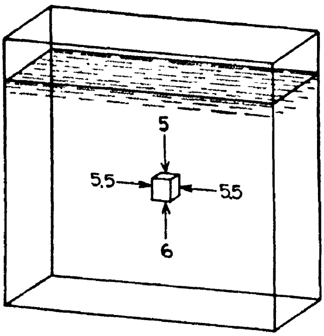

FIG. 263 The pressures on the sides of a 1 cm. cube submerged 5 cm. below the surface of water, are equal There is greater pressure on the lower surface than on the upper

A one centimeter cube of a material heavier than one cubic centimeter of water sinks and displaces a cubic centimeter, or one gram, of water. Because of this displacement it seems to weigh one gram less than it originally weighed. There is a greater pressure (because of greater depth pushing on the bottom of the cube than on the top (Fig. 263). If the force downward is 5 grams and the force upward is 6 grams, the body experiences a buoyant force of 1 gram, which is the weight of the water displaced.

It is very easy to pull ourselves out of water until we are part way out, when we seem to grow heavier. We notice this when climbing from the water into a boat. As long as we are entirely in the water, we can pull ourselves up easily but, when we are nearly out of the water, it is difficult to climb into the boat. It is said that swimmers in the Dead Sea and in Great Salt Lake have difficulty

in keeping the feet under the water because of the buoyancy of the concentrated salt water.

The volume of an irregular object such as a stone which has a specific gravity greater than water may be determined by placing it in a vessel that is completely filled with water. The volume of the overflow is the volume of the body. Or, by Archimedes principle, if we weigh the stone in the air and when under water, the loss of weight of the body as measured in grams is equivalent to the volume in cubic centimeters.

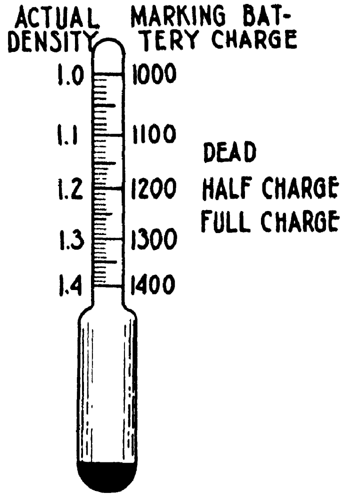

Fig. 264. Storage battery hydrometer (*Foley*)

Specific Gravity. Every automobile driver is familiar with the *hydrometer* used to test the concentration of the acid in the storage battery (Fig. 264). When a battery is fully charged, the liquid should have a specific gravity of 1.275, the figure varying slightly in different makes of batteries. As the battery is discharging, the specific gravity drops and may safely fall to 1.18 without causing any injury to the cells of the battery. Specific gravity is the relation between the weight of an object in air and the weight of an equal volume of water. It is expressed by the following formula:

$$\text{Specific gravity} = \frac{\text{weight of a body}}{\text{weight of an equal volume of water}}$$

In the storage battery this means that the liquid weighs 1.275 times as much as the same volume of water.

As an illustration of the use of the formula we shall solve a simple problem. A piece of brass measuring $1 \times 2 \times 4$ cm. weighs 67.2 grams on a laboratory balance. Its volume is 8 cubic centimeters. Eight cubic centimeters of water weigh 8 grams. Hence 8 cc. of brass compare in weight to 8 cc. of water as 67.2 compares to 8, or the specific gravity of the brass is 8.4

TABLE OF SPECIFIC GRAVITIES

Aluminum	2.7
Brass	8 4
Copper	8.9
Cork	0 2
Gold	19 3
Iron	7 9
Lead	11 3
Mercury	13 6
Oakwood	0 8
Pine wood	0 6
Platinum	21 4
Silver	10.5

WATER PURIFICATION

The problem of securing an adequate and a satisfactory supply of potable (drinkable) water for cities is a serious one. Some cities such as Philadelphia and Columbus (Ohio) secure water from rivers. New York City maintains great reservoirs in the Catskills which are carefully protected from pollution. After purification the water is pumped through the city. Wells are not permitted in congested communities because of pollution dangers. The impurities which get into water as it flows over and through the ground may be classified roughly into suspended material and dissolved material.

Suspended	*Dissolved*
Mud, sand,	Calcium, magnesium, and iron salts,
Leaves, twigs,	Gases,
Bacteria, protozoa,	Chlorides, sulfates, carbonates, and waste products.
Debris from industries,	

Potable water should be free from poisonous substances and disease producing organisms. It should have a pleasant taste and no objectionable odor. There are several methods for the removal of impurities, and most purification systems utilize more than one method. Some of the methods are:

Filtration, for the removal of suspended substances.

Coagulation, for the removal of suspended material and salts.

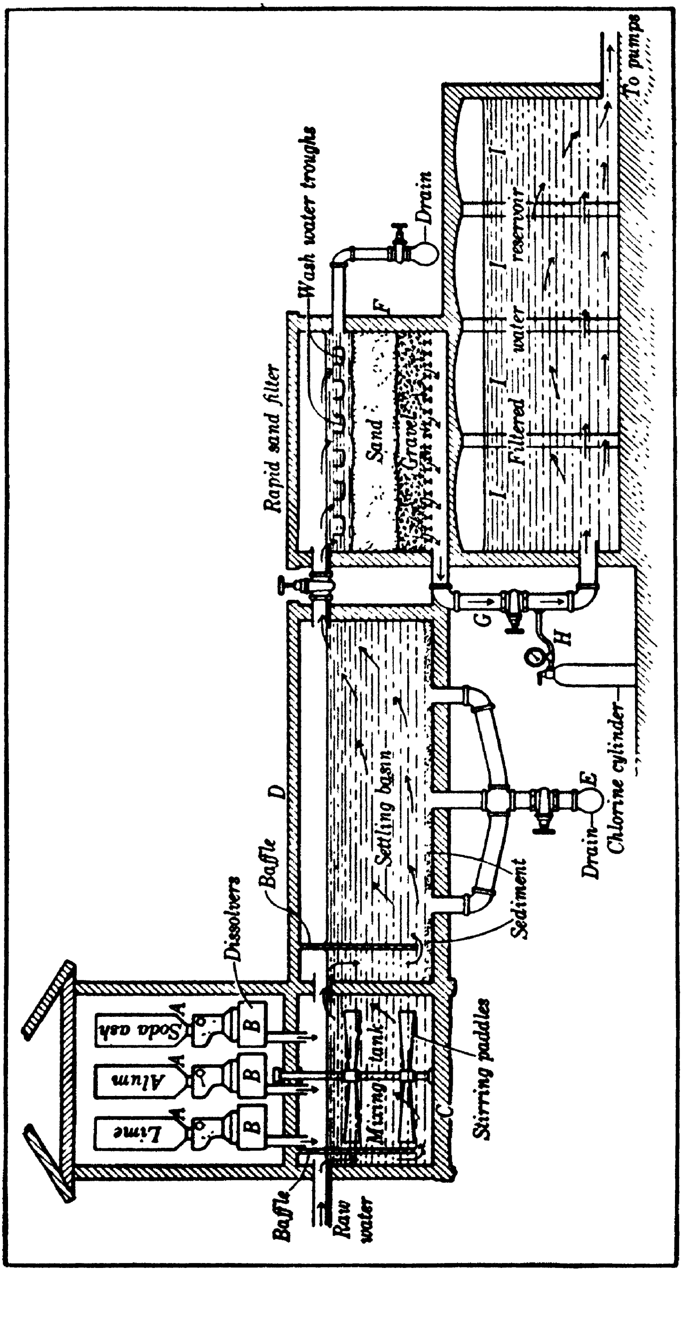

FIG. 265.—Diagram illustrating the operation of a city water purification plant. (From McPherson and Henderson's, "General Chemistry," Ginn and Co.)

Boiling, for the removal of bacteria and protozoa.

Distillation, for the removal of everything but gases and volatile liquids.

Chlorination, for the removal of bacteria and protozoa.

Aeration, for the removal of bacteria and protozoa.

FILTRATION. In a laboratory, suspended matter is removed by filtering through filter paper. This would be much too slow and costly for large volumes of water. The usual city filtration bed consists of a large tank with outlet pipes along the floor. The bottom of the bed is covered with rocks, on which are placed layers of coarse pebbles, gravel and sand, in the order named (Fig. 265). Water flows into the bed at the top, seeps through the sand, which filters out the suspended matter, and leaves the bed through pipes at the bottom. At periodic intervals the flow of water is stopped and the bed is cleaned by forcing water and air in through the bottom. This overflows into the troughs at the top, thus carrying off the accumulated debris with it. At greater intervals, the entire bed is cleaned and refilled.

COAGULATION. Alum and soda are added to water for the purpose of producing a heavy flocculent precipitate of aluminum hydroxide. As this settles out, it carries with it some of the dissolved matter and nearly all of the finely divided suspended material. The water may then be passed into settling tanks and from them to filter beds. Many bacteria and protozoa, trapped in the coagulate, are removed by this treatment.

BOILING. Boiling kills living organic matter and causes soluble bicarbonates of calcium, magnesium and iron to change into insoluble carbonates which precipitate out of solution. In regions of hard water made so by the agency of bicarbonates, tea kettles and boilers become coated with scale. Scouts do, and all campers should, boil all drinking water from a strange source. In some states all water in the vicinity of camp sites and trails is analyzed. Signs are posted in conspicuous places advising of the safety or danger of the water.

DISTILLATION. Distillation differs from boiling in that the steam is passed through condensers and then collected as distilled water. This water, which is of high purity, is used in drug stores,

laboratories, and wherever pure water is required. The process is too slow and expensive for city use. The water is not very palatable having no air or minerals to give it flavor.

AERATION. Water is sometimes sprayed into the air, or allowed to flow down over surfaces that resemble huge shutters, in order to permit a maximum quantity of oxygen to dissolve in it. The oxygen kills bacteria, helps to dispose of some of the other organic matter and rids the water of gases which might give it an unpleasant odor or taste.

CHLORINATION. Chlorine has value as a disinfectant, which is due either to its own properties or to the nascent oxygen it liberates in the presence of moisture. In some cities, iron cylinders of chlorine gas are purchased. The chlorine is allowed to trickle slowly into a small stream of water which carries it to the main body of water. In other cities, chlorine is generated as it is required, by the electrolysis of salt water. In other cases chlorinated lime is used. In each case, the quantity of chlorine added is so small that it should not be noticed by the user.

It is most important that our water supplies be pure, because typhoid bacteria and, perhaps, other disease germs may be borne in the drinking water. Serious epidemics which have swept old and new world cities have been attributed to infected water. Aside from reasons of health, it is important that water contain a minimum of foreign matter. For this reason water should be soft.

HARD WATER

Minerals dissolved in water may interfere with dyestuffs, with tanning, with ceramics, and with many other industrial processes. Hard water produces a hard, heat-resistant coating inside boiler pipes, called scale, which greatly increases the fuel required. For reasons discussed in Chapter 23 we use soap to secure a lathery solution. Certain chemicals which may be present in water, however, react with soap, causing an unpleasant, curdy precipitate to form instead of lather. This scum becomes enmeshed in the clothes making them harsh and gray. It reduces the life of clothing and textiles, generally. It also increases the ex-

pense of laundering, as enough soap must be used to react with all of the chemicals in the water before a lather will be formed.

Water which does not form suds readily with soap is termed hard water. Hardness is usually classified as *temporary* or *permanent*. *Temporary hard water* contains one or more of the soluble *bicarbonates* of *calcium*, *magnesium*, or *iron*. When these are boiled they form the insoluble carbonates which are removed by filtering or settling. Bicarbonates may also be removed by adding slaked lime [calcium hydroxide $Ca(OH)_2$], and filtering. The following equations illustrate the reactions that take place when temporary hard water is softened:

$$Ca(HCO_3)_2 \text{ plus heat} \rightarrow CaCO_3 + H_2O + CO_2$$

calcium bicarbonate forms calcium carbonate water and carbon dioxide

$$Ca(HCO_3)_2 + Ca(OH)_2 \rightarrow CaCO_3 + H_2O$$

calcium bicarbonate + calcium hydroxide → calcium carbonate + water

So-called permanent hard water contains one or more of the chlorides or sulfates of calcium or magnesium. Washing soda (1) or borax (2) will react with these salts to form insoluble compounds which may be filtered off, thus leaving the softened water. Soap itself is a sodium compound and its reactions with hard water forms insoluble calcium and magnesium soaps, (3) mentioned above as the hard water scum.

(1) $$CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 + 2NaCl$$

calcium chloride + washing soda → calcium carbonate + sodium chloride

(2) $$MgSO_4 + Na_2B_4O_7 \rightarrow MgB_4O_7 + Na_2SO_4$$

magnesium sulfate + borax → magnesium borate + sodium sulfate

(3) $$MgCl_2 + \text{soap} \rightarrow Mg(\text{soap}) + 2NaCl$$

magnesium chloride + soap → magnesium soap + sodium chloride.

(The formula for soap has not been included because of the varying compositions of various soaps.)

Automatic water softeners contain a material called *zeolite*, which is a mixture of oxides of sodium, silicon and aluminum. As hard water is passed through these softeners, the calcium and magnesium exchange places with the sodium in the zeolite.

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PROBLEMS

1. What is the weight of one liter of pure water at 4°C.?
2. How many tons of freight can be carried on a barge 20 feet long, 10 feet wide, and 10 feet deep, weighing 5 tons? Answer. 57 tons.
3. 100 cc. of sulfuric acid weigh 182 grams. What is its specific gravity?
4. What is the specific gravity of a piece of wood (pine) $3 \times 6 \times 10$ cm. that weighs 108 grams? Answer. 0.6.
5. A ring weighs 19.4 grams. By using a balance and some water, one can determine whether the ring is gold or brass. How?
6. How would you determine the weight of an irregular piece of iron without weighing it?
7. What is the specific gravity of an object that weighs 48 grams and displaces 8 cc. of water? Answer. 6.
8. What is the weight of a piece of aluminum $3 \times 4 \times 8$ cm.? 260 grams.

VISUAL AID

Motion Picture—BEYOND THE MICROSCOPE. General Electric Co.

EXPERIMENTS

1. Thoroughly mix 10 cc. of concentrated sulfuric acid with 200 cc. of water; fill a Hoffman electrolysis apparatus (both tubes must be completely filled) and connect to a storage battery. Once electrolysis has started do not reverse the terminals. (Unless this precaution is observed, a mixture of hydrogen and oxygen may be formed which is explosive.) The cathode tube should contain hydrogen and the anode oxygen. Identify the two gases by placing a lighted match over the openings and cautiously allowing the gases to escape.

2. Weigh a clean dry iron ball. Fill an overflow can with water until water runs out as additional water is poured in. Place a dry graduated cylinder under the spout of the can; immerse the ball and note how much water has run into the cylinder. Calculate the specific gravity of the ball. Judging from the amount of the overflow, how much do you think the iron ball weighs in water? Verify your answer.

3. Place in three separate tubes 20 cc. of distilled water, of faucet water, and of water containing about 3 drops of calcium chloride. Carefully add soap solution to each tube, counting the drops in each case. Shake the test tubes well after each drop of soap is added, and keep adding soap until a lasting suds is produced. Be careful to distinguish between suds and scum.

(Soap solution may be prepared by dissolving 10 grams of castile soap powder in 1 liter of 50% ethyl alcohol.)

4. Pass carbon dioxide through limewater until the precipitate which is formed completely disappears. Test with soap solution. Is it hard? Boil 20 cc. of the solution for 5 minutes and again test with soap. What type of hardness is this?

5. Add three drops of calcium chloride to 40 cc. of distilled water. Test 20 cc. for hardness. Add washing soda to another 20 cc. filter and again test for hardness. What effect did the washing soda have on the solution?

6. Distill 50 cc of muddy, salt water and test the distillate for hardness. Is the water soft?

26

TEXTILES, CELLULOSE, AND PLASTICS

"Silk, muslin and lace, velvet, satin and crepe
Brocade and broadcloth and other material
Quite as expensive and much more ethereal."
Butler

ANTIQUITY OF CLOTHING

WHO FIRST wore clothes and why? The idea has been advanced that the first clothes, which consisted of hair, leaves, grass, and the like, were worn as a protection against insects. There is no written record of the origin of clothing, and there is no record of the first use of silk, wool, cotton, or linen. They are all mentioned in the Old Testament. The cultivation of silk in China goes back to 2700 B.C. Fragments of nets and cloth 7000 years old have been found in Switzerland. Cotton is mentioned in a Hindu hymn of 1500 B.C.

MODERN TEXTILES

We all realize how clothing styles change from year to year. Few realize that textiles themselves have changed rather recently. Within the past fifty years many synthetic textiles have been developed, so that a person can now clothe himself in chemically made clothing which surpasses the natural fibers in beauty. Textiles may be classified as of plant or animal origin, the former including cotton, linen, and artificial silk, while the latter includes wool and silk. There are, of course, many kinds of hair fibers or wools. There are also many kinds of plant fibers such as hemp, jute, and ramie which are similar to linen.

SILK. Beauty, wealth, mystery, and intrigue have been associated with silk more than with any other fiber. For nearly two

thousand years China held the secret of silk—the Chinese alone knew how to procure it. Many stories have been written of the bribery, murder, and intrigue carried on by Persia and other nations, who resented sending caravans of gold away to China in exchange for silk, which sold for its weight in gold. For nearly five thousand years silk was the raiment of the wealthy and of the rulers of nations. It has been only within the past fifteen years, that, owing to the development of artificial silk, folk in moderate circumstances could wear silk.

Silk is a fiber produced by a certain species of worm as it spins its cocoon. Two tiny fibers, encased in a gummy sheath, are exuded from the worm, in a long, continuous filament. The

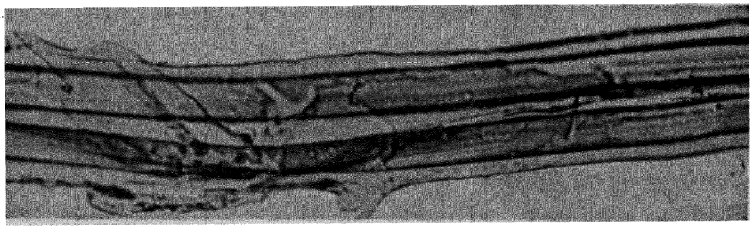


FIG. 266.—Cocoon thread, mulberry silk. × 500. (*Courtesy Mr. Howard A. Walter, Phila. Textile School.*)

cocoons are softened, the filaments unwound, and several filaments are twisted together to form a thread. Silk from mulberry-fed worms is light and of fine quality. So-called wild, or Tussah silk, is tan colored, can not be bleached, and is coarser in quality. It is made into pongee, plush, and imitation seal skin.

Silk fibers are smooth, nearly transparent tubes which reflect light in almost parallel rays giving a high luster (Fig. 266). It is the strongest of the textile fibers, is a poor conductor of heat and, while very hygroscopic in the raw state, in the finished and dyed condition is a poor absorbent of moisture. Silks are worn in summer because of their beauty and light weight. Light colors are worn in summer because they reflect heat; dark colors absorb heat. Silk can be bleached very white. Being a poor conductor, however, silk is not the coolest textile to wear. Salts of tin and aluminum may be added to silks to "weight" them, and make them feel heavier than they really are.

WOOL. Wool is another textile of animal origin. It is a protein, containing carbon, hydrogen, oxygen, nitrogen, and sulfur. (Silk is similar, chemically, except that it contains no sulfur.) The individual fibers are covered with a tiny, scale-like sheaths, which produce a rough appearance and a dull luster (Fig. 267). They are the weakest of all the common fibers. The sheaths or scales make it difficult to weave closely, so that the finished cloth is apt to be coarser than cotton or silk. Wool, being a poor conductor, and the air trapped between the sheaths and within the rather coarse weave also being a poor conductor, it is a suitable textile for winter wear, as it prevents loss of body heat. Because it retains moisture longer than the other textiles, it is suitable for bathing

FIG. 267. Wool. × 500. (*Courtesy Mr. Howard A. Walter, Phila. Textile School.*)

suits and other uses where a rapid evaporation of moisture might chill the body.

FUR. By definition, textiles are woven materials. Fur, and rubber are included in this chapter, however, owing to their similarity of composition and use. Fur differs very little in most respects from wool, as both are the hairy coverings of animals. In general, it has the same characteristics as wool, except that more dead air space is available, making fur the best non-conductor of heat and the warmest wearing apparel. All furs are about equally efficient in retaining body warmth; their relative costs are dependent upon their durability and their beauty. For that reason, many less desirable furs are trimmed and dyed to resemble a more costly fur. The hair of each animal is more or less characteristic of that animal and differs from that of other animals. A microscopic examination of the hair will usually reveal its identity. Fur will give the same chemical tests as wool. It should be kept rather cool to maintain its beauty (Fig. 268).

Linen. Linen comes from the inner bark of the flax plant. It consists of short, cylindrical, transparent, tubular threads, placed

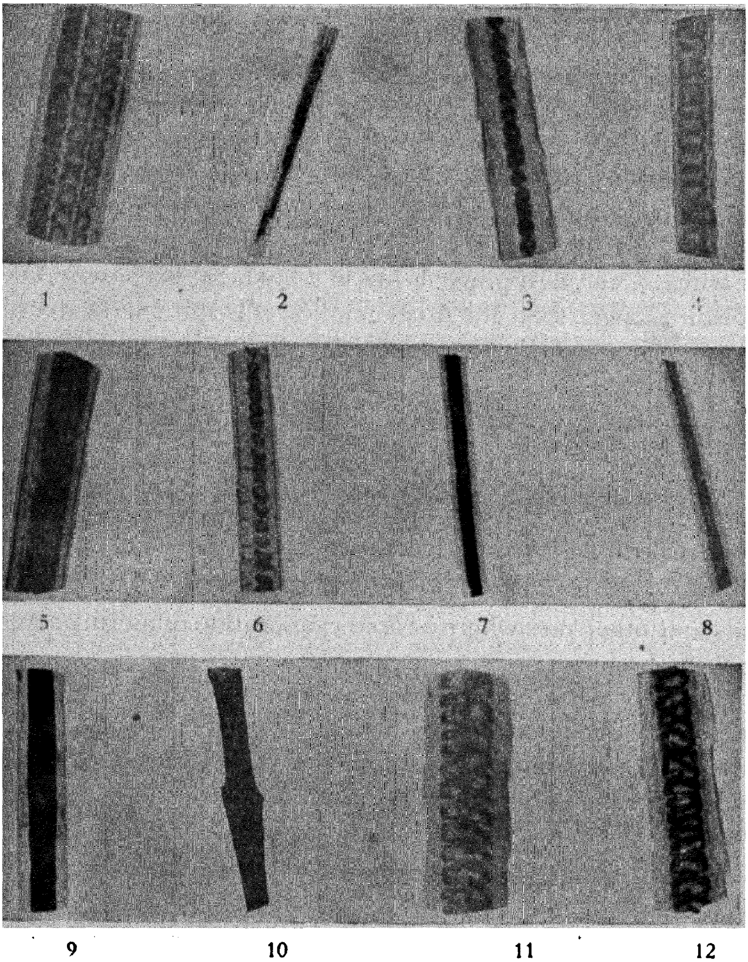


Fig. 268.—The microscopic appearance of the hairs of certain animals. 1, chinchilla rabbit; 2, white rabbit; 3, guinea pig; 4, grey squirrel; 5, Persian cat; 6, Persian cat; 7, dog; 8, dog; 9, natural sable; 10, Russian sable; 11, Alaska fur seal; 12, aye-aye. (*From Smith and Glaister's "Recent Advances in Forensic Medicine."*)

end to end. Under the microscope, linen fibers resemble corn stalks or bamboo (Fig. 269). It is cellulose, hence it consists of carbon, hydrogen, and oxygen. Linen is not as strong as silk, but is

stronger than cotton. It wets readily, the moisture spreading rapidly from fiber to fiber. It is the best conductor of heat and is permeable to air, therefore it is the most comfortable material for summer wear. Linen contains little or no lint, which fact, along with the ease with which it conducts moisture, makes it ideal for bandages and towels. Its smooth fibers do not readily become dirty. It does crumple easily, but launders well. Russia supplies

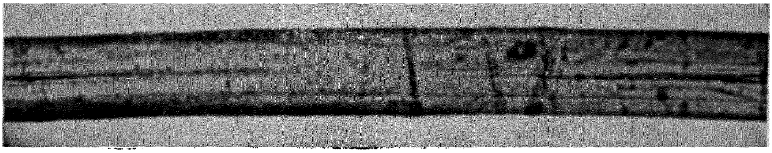


Fig. 269.—Linen. × 500. (*Courtesy Mr. Howard A. Walter, Phila. Textile School.*)

most of the world's linen. Other nations supplying it are Ireland, Belgium, Holland, and Germany. Most of the flax produced in the United States is raised for its seed, rather than for its fiber. The seed is made into linseed oil, a drying oil in paint.

Cotton. Commercially, the most important textile fiber in the United States is cotton, "King Cotton." Cotton consists of hollow tubes of cellulose which are slightly flattened and twisted

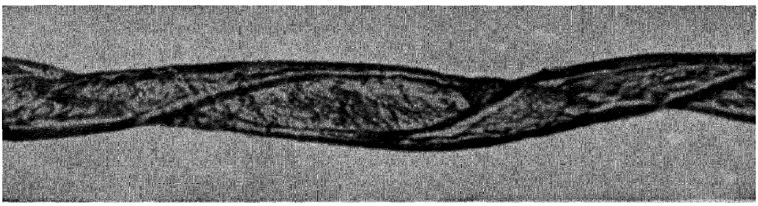


Fig. 270.—Cotton. × 500. (*Courtesy Mr. Howard A. Walter, Phila. Textile School.*)

(Fig. 270). Herodotus referred to cotton plants as wool trees. It is a better heat conductor than silk or wool, but poorer than linen. It is weaker than either silk or linen. It is a poor absorbent of moisture but it may be improved by boiling in alkali, which makes it suitable for surgical dressings. It is possible to weave cotton fibers very closely. The value of a piece of cotton cloth depends upon the length of the individual fiber, the number of

fibers twisted together, and the number of threads woven in each direction per square inch. Being a fair heat conductor and offering little dead air space, it is comfortable for summer wear but not for winter. Fluffy, woolen-looking blankets are now being made of cotton, but are inferior to wool both as to warmth and laundering qualities.

Cotton fibers are attached to the seed of the plant. Their removal from the seed by hand was a slow process. Whitney, in 1794, invented the cotton gin, a device for the mechanical removal of fiber from seed. This invention and that of the spinning jenny resulted in the great cultivation of cotton in the United States. When the gin removes the cotton fibers from the seed, it leaves a covering of short linters. Linters are removed for various uses and recently a new machine has been invented which gives an exceptionally close shave to seeds. For years the seeds were a nuisance but now, cottonseed oil, an important by-product, is extracted from them. Hydrogen gas under great pressure and at a high temperature is passed into the oil, in the presence of nickel dust, and combines with it to form cooking fats, such as Crisco and Spry. The nickel dust is used as a catalyst (see p. 127) and is removed.

CELLULOSE

Many of our modern materials both for home and industry result from man's utilization of cellulose—one of Nature's mystery substances. Cellulose is composed of carbon, hydrogen, and oxygen, built into huge molecules. The formula for soluble starch has been given as $C_{1200}H_{2000}O_{1000}$. Cellulose molecules are even larger than starch molecules and are bound together with a cementing material, thus forming the framework of all plant structures. We find cellulose in such varied substances as wood, cotton, linen, and celery. Man is unable to digest cellulose, but cattle and other herbivors can utilize it.

Cellulose makes possible the substance, paper, which has aided civilization as much as any other material. Without it we might still be using clay and stone tablets. Cellulose is also a constituent of such materials as rayon, cellulose acetate, "Duco,"

collodion, guncotton, manufactured leather, cellophane, and photographic films.

Most cellulose is produced from spruce wood. Logs are chipped in huge revolving drums. The small pieces of wood are heated with chemicals and the result is a mass of soft white fibers resembling cotton wool. In the production of paper, these fibers are mixed with a binder and pressed by hot metal rolls. For fabrics, a solution of the compound cellulose xanthate is heated and forced through a sieve into dilute acid, producing a mass of silky threads called *rayon*. All varieties of rayon including such

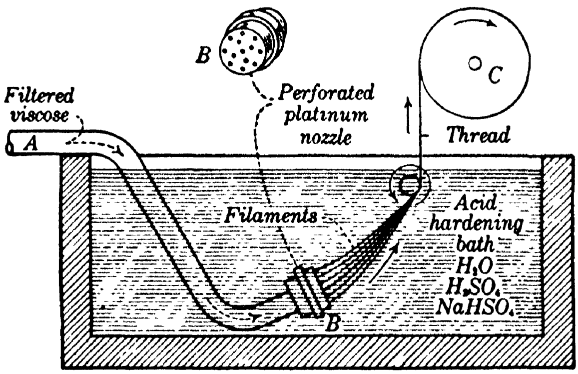


FIG. 271.—Making rayon threads. Pure cellulose, dissolved in a solvent is forced through small holes in B and emerges into the hardening bath as a mass of fine threads. (*From McPherson and Henderson's "Chemistry for Today," Ginn and Co.*)

trade names as *Bemberg*, *Acetate*, *Viscose*, *Celanese* are produced by some chemical treatment of cellulose fibers (Fig. 271). Within the last few years, manufacturing methods have been improved to such an extent that rayon materials replace silk for most purposes. Because of the method of manufacture, the threads have a luster equal to silk. At present about 500,000,000 pounds are manufactured each year and the rayon products have become so important that they are serious competitors of the silk industry.

CELLULOSE NITRATES AND ACETATES

Many years ago it was discovered that, when cellulose is treated with about fifty times its weight of a mixture of nitric and

sulfuric acids, it is converted into various nitrates, the type depending upon the temperature and treatment. The highest nitrate, containing about 14% nitrogen, it termed guncotton. This material, resembling cotton wool, is a violent explosive. If, however, the nitration is less complete, a nitrate is produced which when dissolved in a mixture of ether and alcohol forms *pyroxylin*. This material forms collodion and, when combined with camphor, celluloid.

Perhaps the greatest use of pyroxylin is in the manufacture of motion picture film. The material in solution is poured over a

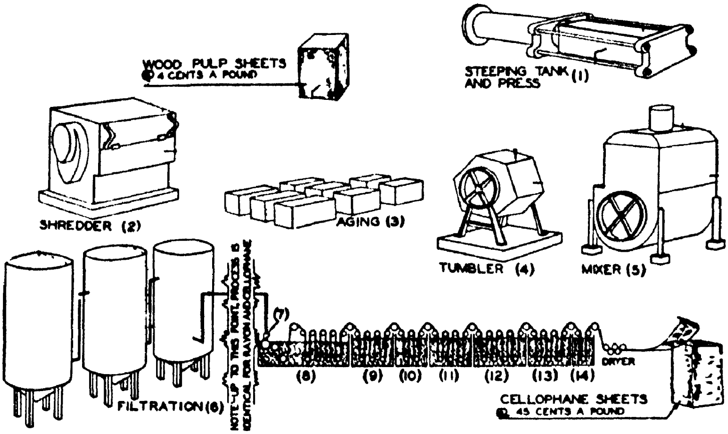


FIG 272.—Manufacture of cellophane from wood pulp. (*Courtesy Fortune Magazine*)

large table. When the solvents evaporate, the film is cut into strips and sensitized. Unfortunately, the film burns vigorously, so that it must be carefully guarded in theaters. On the other hand, cellulose dissolved in acetic acid forms safety film. Most of the educational films are of this material. It burns slowly and the products of combustion are less dangerous than are those of the cellulose nitrate.

CELLOPHANE. Cellophane is a substance which has had a more rapid and diversified development than perhaps any other one substance. It now wraps, beautifies, and protects almost everything. In France, it is even being made into motion picture film with some success.

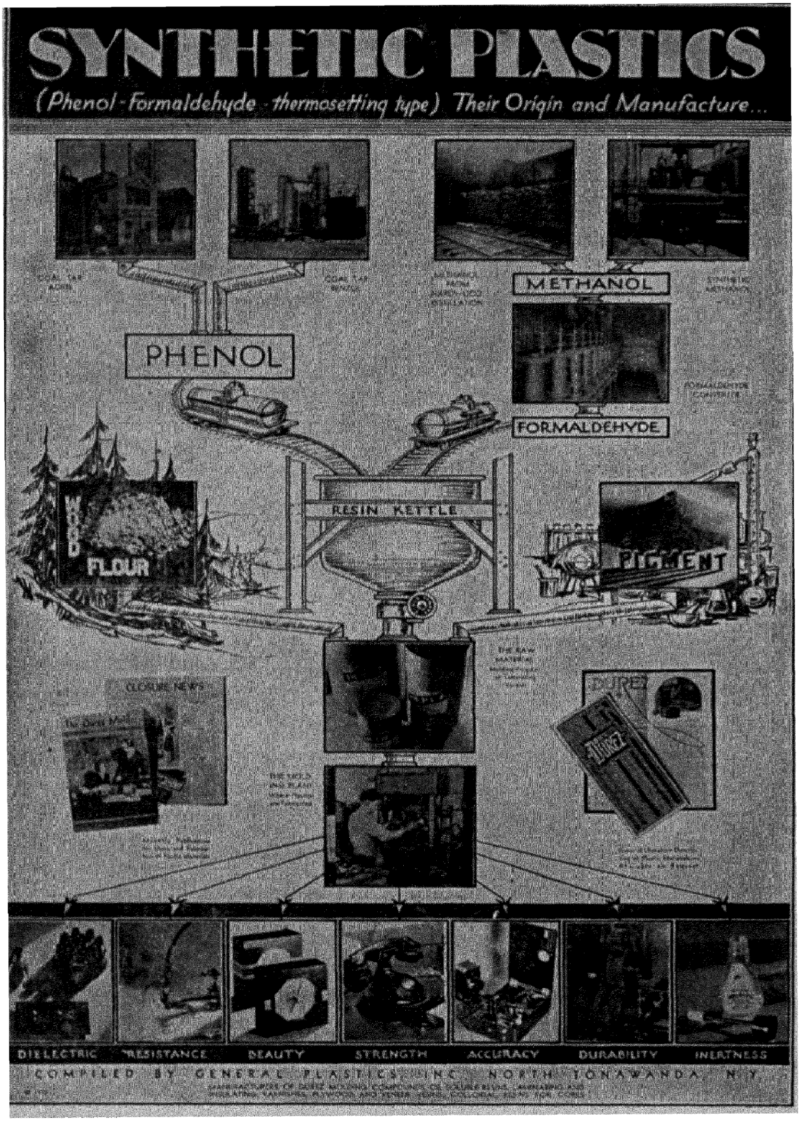
The history of cellophane seems to be as follows: In 1900, Brandenberger in France, began his attempts to produce a table cloth which would be impervious to dirt. He tried coating cotton with viscose, without, however, succeeding in making his table cloth dirtproof. He did discover that a thick, brittle sheet of film could be made. By 1912 he had perfected his process to the point of producing a thin, pliable, transparent film or sheet. Getting some rayon manufacturers interested, he produced cellophane in commercial quantities. His product was so expensive that it was used to wrap only very expensive perfumes, candies, and such articles. (See Fig. 272 for a description of the manufacture of cellophane.)

LACQUERS

Solutions of pyroxylin with rosin or resinous substances are called lacquers. Such solutions often contain aluminum or bronze powder and are used in painting metal objects, radiators, walls, and other substances, to give tham a protective metallic covering. Amyl acetate is one of the best solvents as it dries more rapidly than ordinary paint, yet slowly enough to permit a smooth, uniform covering. "Duco" and "Opex" are two well known examples of this class of products. Two or three weeks time were formerly required to paint an automobile, whereas two or three days are sufficient with the new lacquers. This results in a big saving in drying space and expense. These new lacquers will last much longer on automobiles, are tougher and permit a wide variety of colors to be used. The use of these lacquers is extending to furniture and interior decoration.

PLASTICS

Some say we are now entering the age of alloys and others say that we are entering the age of plastics. Certainly both are being rapidly developed at present and truly marvelous results are being attained. Just a few of the many types of plastics will be described here. Plastics are materials which may be molded into forms that will become hard and permanent. It is possible to



SYNTHETIC PLASTICS
(Phenol-Formaldehyde thermosetting type) Their Origin and Manufacture...
METHANOL
PHENOL
FORMALDEHYDE
RESIN KETTLE
WOOD FLOUR
PIGMENT
DUREZ
DIELECTRIC
RESISTANCE
BEAUTY
STRENGTH
ACCURACY
DURABILITY
INERTNESS
COMPILED BY GENERAL PLASTICS INC NORTH TONAWANDA N.Y.

FIG. 273.

soften some of them after they have hardened but some remain hard. Most of them are very tough, may be polished, and may be dyed in a great variety of colors (Fig. 273). Just recently a plastic called Plexolite has been developed that has many of the properties of glass.

BAKELITE. In 1909, Baekeland announced the discovery of a new plastic material, which he made by heating carbolic acid and formaldehyde with steam in a closed kettle. Four types of Bakelite products are on the market at present.

(*a*) Bakelite, as formed in the initial reaction between carbolic acid and formaldehyde, is heated under pressure at about 150°C. for several hours. A hard, insoluble, infusible, and very strong product results. It is light, burns in a flame, and is made into clocks, pipes, beads, umbrella handles, and laboratory ware.

(*b*) Molded products are made by thoroughly mixing Bakelite resin with wood flour and heating it in molds under great pressure. The heat causes the resin to melt into and impregnate the cellulose, thus forming a very dense, hard, infusible object, which, usually, has a high polish as it comes from the mold. Examples of this product are billiard balls, gear shift handles, radio parts, and knife handles.

Wood flour is made by grinding chips, shavings, and sawdust to a fine powder. At present about twenty five thousand tons of wood flour are made each year. It is used in making plastics, explosives, linoleum, and hundreds of other articles. This is but one of many examples which illustrate the economic advantage of scientific research. Through scientific research, many waste products are being turned into profit. In the Chemistry Leaflet for December 18, 1930, there is a picture of a huge refuse burner which has been idle since 1924. For sixteen years that burner consumed the equivalent of about 560 cords of wood each day. The sawdust and odd scraps of wood, which it was customary to burn, are now being converted into valuable products.

(*c*) Laminated Bakelite made from paper is used as radio panels, doors, partitions, and small panels. When cloth is used as a foundation material, the product is employed for silent gears. It is stronger than cast iron and unaffected by water or oil. Paper or cloth is impregnated with a solution of Bakelite resin and sub-

jected to high pressure and heat. The sheets are fused together into hard, tough boards of great strength. In fact, they are so completely fused together that it is impossible to recognize their individual layers.

CASEIN PLASTICS. Fountain pens, automatic pencils, buckles, buttons, tobacco holders, radio parts, electric switch plates, cutlery handles, toilet articles, and ornaments are being made from another new plastic called Karolith. It is made from milk casein and formaldehyde. It was developed in the United States within the past five years, and is very hard, smooth, uniform in texture, and takes a high polish. This plastic is odorless, non-inflammable, and may be dyed any color. Moderate heat or moisture softens it, thus making bending, embossing, and molding possible. It is hygroscopic and, for that reason, may not be used under certain conditions.

RUBBER

When Columbus discovered America, he found the natives using a strange, elastic, gummy substance for clothing. They also made the substance into balls which bounced on the ground. In 1731, La Condamine discovered the natives of Brazil playing with similar balls. This gum was investigated by the French but little attention was paid to it. It received its modern name by a mistake. Priestley is reported to have discovered that a wad of the gum would erase pencil marks. He called it, on that account, "rubber," which name is now universally accepted.

Rubber comes from the sap of certain tropical trees, Hevea Braziliensis being one example. It is coagulated into lumps or sheets, dried, mixed with fillers and coloring matter, calendered, vulcanized, and made into manufactured goods. Fillers include colors, agents to hasten vulcanization, agents to reduce stretching and oxidation, and adulterants. During vulcanization, rubber reacts with sulfur, producing a flexible, elastic material which does not become sticky or brittle with extreme temperatures. The reason that rubber articles tarnish silver is that the sulfur in rubber reacts with silver, thus forming dark silver sulfide. Rubber slowly oxidizes, and becomes brittle. It also is attacked

by strong acids, the halogens, and other substances. Properly made rubber, fabricated with cotton, makes one of the toughest, most durable materials known. No other flexible material can stand the punishment given an automobile tire, for instance.

SYNTHETIC RUBBER. Chemists had long wished to produce rubber in the laboratory. They knew that when rubber (caoutchouc, $(C_5H_8)_x$) was heated, it decomposed into the liquid, isoprene (C_5H_8). Although isoprene was well known, it seemed impossible to reverse the process and synthesize it into the polymer, rubber. During the World War both Germany and Great Britain synthesized isoprene into rubber, but the product was not durable and the cost was great. Not until 1931 was synthetic rubber developed for commercial purposes. In its production coal and limestone are heated in an electric furnace, forming calcium carbide. When calcium carbide comes in contact with water the gas, acetylene, is formed. This gas is the base for modern synthetic rubbers. When a polymer of this gas (vinyl acetylene) is mixed with hydrochloric acid, a product called *chloroprene* results. From this material comes Neoprene. It should be emphasized that Neoprene is not the same chemical compound as natural rubber. Because of this fact it is more resistant to oxidation and to the effects of oils and gasolines. Although more expensive than natural rubber it is rapidly assuming an important place in industry. The chemist has finally made rubber in the laboratory!*

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PROBLEMS

1. What is collodion? Why is it called "new skin"?
2. What is the difference between gun cotton and collodion? gun cotton and cellophane?
3. What is one of the disadvantages of cellophane?
4. Suggest a use to which it may not be put on account of this disadvantage.
5. What is a plastic?
6. Name 3 plastics. Suggest a way to identify each.
7. Despite the fact that strong washing soda will remove dirt from clothes, why is its use inadvisable?
8. How determine whether a cloth is all or only part wool?
9. How would you distinguish between real fur and fur made from cotton?

TOPICS

Silk Worm Culture.
Silk Weighting.
The Discovery of Vulcanization.
Products Derived from Cotton.
Neoprene
Rayon Manufacture.

EXPERIMENTS

1. Examine pieces of unknown textiles, using the tests given in the chart. Make a written report, pasting to it a piece of your unknown material with one corner burned. All cloth should be boiled in water to remove sizing and dried before it is tested.

2. To distinguish three types of cellulose silks:

(1) Boil 0.2 grams of silk in 2 cc. Benedict's reagent for ten minutes. Fill tube with water.

(*a*) Nitrocellulose immediately turns bright blue.
(*b*) Cuprammonium and viscose do not change color.

(2) Cover your sample of cloth with zinc chloride—iodine reagent, pour off the reagent and cover with water.

(*a*) Cuprammonium silks turn a fugitive brown.
(*b*) Viscose turns a bluish green.

3. To distinguish between cotton and mercerized cotton, dissolve 0.5 gram of potassium iodide and 0.5 gram of iodine crystals in 20 cc. water. Dissolve 25 grams of zinc chloride in 15 grams of water. Soak the sample of cloth in a mixture of the two solutions for 3 minutes. Wash it until the brown color disappears. Place sample in clear water. The blue color disappears from cotton in 5 minutes while mercerized material remains blue for nearly an hour.

	Cotton	*Linen*	*Wool*	*Silk*	*Artificial Silk*
Singe one corner of a patch—paste it here					
Does it burn readily?	Yes	Yes	Crinkles	Crinkles	Yes
Odor	Burning paper	Burning paper	Burning hair	Burning hair	Depends on its kind
Diagram of fiber .	Twisted	Bamboo-like	Scales	Smooth tube	Smooth tube
"Wet Test" Moisten finger tips—apply—does cloth wet readily? .	No	Yes	Yes	No	No
10% NaOH—boil 10 min . . .	No effect	No effect	Dissolves	Dissolves, cultivated in 10 min., wild in 60 min.	No effect
Conc HCl	Disintegrates slowly	Disintegrates slowly	No effect	Dissolves rapidly	
HNO_3 . .	No color	No color	Yellow	Yellow	
Conc. H_2SO_4 (do not boil)	Disintegrates with charring	Slowly	Slowly	Rapidly	
NaOH and $Pb(C_2H_3O_2)_2$	No effect	No effect	Black	No effect	No effect
Millon's reagent	No effect	No effect	Red	Red	No effect
Boil in water—dry thoroughly; immerse in glycerin	Opaque	Transparent			
Alcoholic cochineal 15 minutes. .	Bright red	Violet red			

Preparation of reagents.

10% Sodium Hydroxide. 10 grams of sodium hydroxide are dissolved in 90 cc. of water.

Lead Acetate. 10 grams of lead acetate in 90 cc. of water.

Alcoholic Cochineal. Add 1 gram of cochineal to 50 cc. alcohol. In 10 or 15 minutes, filter. Allow the sample to remain in this solution for 15 minutes.

Millon's Reagent. Dissolve 15 grams of mercury in 30 cc. concentrated nitric acid. When completely dissolved, add 70 cc. water. *This is poisonous and corrosive; great care must be exercised in handling it.*

Benedict's Reagent. Dissolve 85 grams of sodium citrate and 50 grams of anhydrous sodium carbonate in 400 cc. water. Dissolve 8.5 grams of copper sulfate in 50 cc. of hot water. Pour the copper sulfate solution into the citrate-carbonate solution. Stir it well. To use it add about 2 cc. of the reagent to the material to be tested and bring to a boil.

Zinc Chloride--Iodide. Dissolve 2 grams potassium iodide and 0.1 gram iodine crystals in 5 cc. water. Dissolve 20 grams zinc chloride in 10 cc. water. Mix the two solutions just before using.

27

THE FUTURE OF SCIENCE

IN THE preceding pages we have described some achievements of the physical sciences as they relate to the every-day life of the reader. Each topic has been chosen with a view to the coordination and expansion of the student's knowledge. No doubt there are many other topics which should have been included. Yet it is manifestly impossible to cover the whole field of scientific knowledge in a brief survey.

Science, because of its complexity, has been separated into several divisions and these in turn into other subdivisions. The principal divisions, physics, chemistry, astronomy, biology, mathematics, and geology have been further divided for convenient study.

We list below a few examples of these subdivisions.

Physics	*Chemistry*	*Biology*
Mechanics	Inorganic	Zoology
Heat	Organic	Botany
Sound	Physical	Genetics
Light	Bio-chemistry	Anthropology
Electricity	Physiological-Chemistry	Ecology
Astro-Physics	Colloidal-Chemistry	Parasitology
Bio-Physics		Immunology
Mathematical-Physics		Cytology

In the present text no sharp division of material has been made inasmuch as the purpose of the survey is to give the student an elementary view of the entire field of physical science.

WHAT OF THE FUTURE OF SCIENCE?

The student has without doubt discovered that many of the phenomena which have been discussed still lack a satisfactory explanation. We know that "ultimate truth" is beyond the ability of man, inasmuch as each new scientific discovery opens

a complete new field of investigation. Someone has compared a scientific investigator to a person placed in a room having many closed doors. By patient effort a key is found which opens one door. However, this opened door simply leads to another room also full of closed doors, each needing a special key.

Nevertheless, we can describe with some assurance some of the problems that the scientist of tomorrow must face. As this is written, the world is suffering from an unsatisfactory distribution of food. Some people have too much food and clothing while millions of persons go hungry and ill-clad. The chemist is working vigorously on the problem of synthesized food. He knows that in some manner CO_2 and water combine in the presence of the catalyst, chlorophyll, and sunlight to form starch. If the chemist can discover a way of producing starch cheaply in the laboratory, there will be plenty of food. Likewise, a synthesis of protein and fats might free us from the high cost of meats and oils. There arises the question, will man be able to adjust his social structure so as to distribute this abundance properly? The trained mind of the future must meet this problem.

While studying this book the thinking student has without doubt been amazed at the rapid progress which science has made in constructing devices for our comfort. We ride in luxurious automobiles, trains, and airplanes. We live in electrical homes where we can have our choice of climate at the flip of a switch. We now have our choice of the entertainment of the world by the radio, and we shall soon see great events by television. Our foods are rushed from all parts of the world to our table. We eat, in winter, luscious fresh fruits and vegetables which are prepared by the new "Dry Ice" process. The medical specialists perform miracles in saving human life and in making our lives more comfortable.

Yet with all this progress most of us are not happy. The young man finds difficulty in starting a career by which he can secure for himself a comfortable existence and a competance for his old age. Most of our present day industries are tremendous corporations and the young man finds himself a slave to a remorseless machine which drives him at a furious pace so that he is worn out and useless at middle age.

The hospitals and sanitoriums are filled with mentally ill people who have not been able to withstand the pressure of our modern civilization. Although science has increased the life expectancy of man by saving the lives of most young children and by repairing the decay of middle age, yet it has not made the world a happy place in which to live. We live in an atmosphere of fear for the future. Despite the luxuries which science has provided, most of us are not certain that we can escape poverty as we grow older. Science has provided luxury and comfort; it must now devise means for making a measure of comfort available to all.

Many diseases remain unconquered. Cancer and heart disease seem to be increasing. Infantile paralysis (poliomyelitis) and other infectious diseases are still unconquered. The common cold still remains a puzzle. Scientists have now realized that medicine must enlist the aid of physics and chemistry as well as biology if it is to solve the problems of the future. Many scientists are now working in groups, each adding his knowledge and ingenuity to the complex problem.

We may expect great advances in the healing art in the future. This is to be expected since the sciences of inert objects have thus far outstripped the science of the human body and the mind. Man will learn to understand himself better within the next few years.

We live in an age of commercialized recreation. We dash about in automobiles to football and baseball games, where thousands of people gather in great mobs. All of us listen to the same music, see the same theatrical performances, and wear the same types of clothes. One goal of scientific research should be to provide wholesome recreation and interesting avocations which will provide relaxation from the strain of modern life.

RESEARCH OF THE FUTURE

In the future, the research facilities of the world will undoubtedly increase. At present many millions of dollars are spent each year in scientific and medical investigation.

The great research laboratories such as the Bureau of Standards, The Mellon Institute, The General Electric Company, the Eastman Kodak Company, and the various college and university laboratories are producing marvelous results in all fields of science. Science will in the future no doubt offer a wider field of opportunity for the trained student than in the past.

It is still true that the student who has mastered the fundamental principles of science will be able to adjust himself to new technical developments. For example, a scientist with an excellent background in chemistry will be valuable to any new industry which may develop in that field. The man who has learned to think will still be of value to society.

The astronomer, physicist, and chemist will no doubt produce startling discoveries concerning the nature of the universe. Some of these may revolutionize our present civilization. One might list a few developments which seem imminent.

Perfected television.
Artificial radioactivity.
Solution of the cancer problem.
New ideas of the origin of the universe.
New alloys and machines.
Safer and speedier transportation.
Freedom from contagious diseases.
Many new electrical conveniences.
Better and cheaper homes.

EDUCATION OF THE FUTURE

There is great unrest in the field of education. The citizens of communities are analyzing the cost of education and are inquiring whether the present methods of education justify the money expended. Most parents desire that their children shall have a college education. Does our modern college fulfill this need or will the educational plant of the future be radically different? Some educators are of the opinion that all college courses will be of the survey type rather than a departmentalized set of subjects.

Certainly there are students who do not satisfactorily respond to the present curriculum. Will the college of the future be able to provide for all students who wish to secure a college education? Will there be ample opportunities for vocational work and practical skills as well as for mental discipline? The educational research indicates that the college of the future will set up other standards for admission than secondary school credits. In fact, the new ideas will probably permeate the secondary schools, for here also there are many maladjusted students.

The scientist must solve this problem of mass education in the very near future if our present social order is to continue. However, one may look with confidence to the future, believing that science will continue to provide better means for happier living.

APPENDIX I

A course in Physical Science may be greatly enriched by the use of films, displays, and other visual material. "One picture is worth a thousand words." It is impossible to evaluate all of the visual material offered the teacher of science. For this reason only a few motion pictures are listed at the end of some of the chapters. Some of these have been used by the author and found to be very instructive.

A few general sources of visual material are listed here, from which a teacher may select.

Eastman Classroom Films (16 mm., safety film) may be purchased from the Eastman Kodak Co. They may be rented from the Bucknell Classroom Film Library (Bucknell University, Lewisburg, Pa.) and from the Massachusetts Department of Public Instruction.

"Enriched Teaching of Science in the High School" Woodring, Oakes, and Brown ($2.75, Bureau of Publications, Teachers College, Columbia, New York) contains a wealth of suggestive free and low cost materials of many kinds.

The University of Chicago is making a number of films of interest to science teachers.

Valuable films, and other material may be secured from various State Departments of Public Instruction, Public Health, and Bureaus of Mines.

Educational Screen, a monthly magazine published at 64 E. Lake St. Chicago, Illinois.

One-thousand-and-one-film list, published by Educational Screen.

Keystone View Co., Meadville, Pa.

Spencer Lens Co. 19 Doat St. Buffalo, N. Y.

The General Electric Company provides many films free of charge.

APPENDIX II

WEIGHTS AND MEASURES

1 inch = 2.54 centimeters
1 mile = 1.609 kilometers
1 cubic inch = 16.387 cubic cm.
1 ounce (av.) = 28.3495 grams
1 lb. (av.) = 453.59 grams
1 quart = 0.946 liters
1 gallon = 3.785 liters

1 meter = 39.37 inches
1 kilometer = 0.62 mile
1 cubic meter = 35.314 cu. ft.
1 kilogram = 2.2 lbs. (av.)
1 liter = 1 06 liquid quart
1 cubic centimeter = 0.061 cu. in.

UNITS

Wave length of sodium light .00005896 centimeter.
1 Horse Power = 550 foot pounds per second.
1 Ångström = 1000 X-units.
1 Light-year = 6 million million miles
1 gram atom contains 6×10^{23} atoms.
Diameter of an atom about 10^{-8} cm.
Mass of an electron 9×10^{-28} grams.
Diameter of an electron 10^{-13} cm.
Velocity of light 3×10^{10} cm/second.

APPENDIX III

RELATIVE HUMIDITY BY WET AND DRY BULB DETERMINATION

Dry Bulb	Difference between Dry and Wet Bulb Thermometer																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	20
						Per Cent of Relative Humidity													
30	89	78	67	56	46	36	26	16	6										
32	89	79	69	59	49	39	30	20	11	2									
34	90	81	71	62	52	43	34	25	16	8	1								
36	91	82	73	64	55	46	38	29	21	13	5								
38	91	83	75	66	58	50	42	33	25	17	10	2							
40	92	83	75	68	60	52	45	37	29	22	15	7	0						
42	92	85	77	69	62	55	47	40	33	26	19	12	5						
44	93	85	78	71	63	56	49	43	36	30	23	16	10	4					
46	93	86	79	72	65	58	52	45	39	32	26	20	14	8	2				
48	93	86	79	73	66	60	54	47	41	35	29	23	18	12	7	1			
50	93	87	80	74	67	61	55	49	43	38	32	27	21	16	10	5	0		
52	94	87	81	75	69	63	57	51	46	40	35	29	24	19	14	9	4		
54	94	88	82	76	70	64	59	53	48	42	37	32	27	22	17	12	8	3	
56	94	88	82	76	71	65	60	55	50	44	39	34	30	25	20	16	11	7	0
58	94	88	83	77	72	66	61	56	51	46	41	37	32	27	23	18	14	10	3
60	94	89	83	78	73	68	63	58	53	48	43	39	34	30	26	21	17	13	6
62	94	89	84	79	74	69	64	59	54	50	45	41	36	32	28	24	20	16	9
64	95	90	84	79	74	70	65	60	56	51	47	43	38	34	30	26	22	18	12
66	95	90	85	80	75	71	66	61	57	53	48	44	40	36	32	29	25	21	15
68	95	90	85	80	76	71	67	62	58	54	50	46	42	38	34	31	27	23	17
70	95	90	86	81	77	72	68	64	59	55	51	48	44	40	36	33	29	25	20
72	95	91	86	82	77	73	69	65	61	57	53	49	45	42	38	34	31	28	22
74	95	91	86	82	78	74	69	65	61	58	54	50	47	43	39	36	33	29	24
76	96	91	87	82	78	74	70	66	62	59	55	51	48	44	41	38	34	31	26
78	96	91	87	83	79	75	71	67	63	60	56	53	49	46	43	39	36	33	28
80	96	91	87	83	79	75	72	68	64	61	57	54	50	47	44	41	38	35	29
82	96	92	88	84	80	76	72	69	65	61	58	55	51	48	45	42	39	36	31
84	96	92	88	84	80	76	73	69	66	62	59	56	52	49	46	43	40	37	32
86	96	92	88	84	81	77	73	70	66	63	60	57	53	50	47	44	42	39	34
88	96	92	88	85	81	77	74	70	67	64	61	57	54	51	48	46	43	40	35
90	96	92	89	85	81	78	74	71	68	65	61	58	56	53	50	47	44	41	37
92	96	92	89	85	82	78	75	72	68	65	62	59	56	53	50	48	45	42	38
94	96	93	89	85	82	79	75	72	69	66	63	60	57	54	51	49	46	43	39
96	96	93	89	86	82	79	76	73	69	66	63	61	58	55	52	50	47	44	40
98	96	93	89	86	83	79	76	73	70	67	64	61	58	56	53	51	48	46	41

Example: The wet bulb reads 70 and the dry bulb reads 78. There is a difference of 8 degrees. We read down the left column to 78 and then across to the column headed 8. The figure 67 is found at the junction of the two lines, therefore the relative humidity is 67%. In other words there is just 67% as much moisture as it is possible at a temperature of 78°.

APPENDIX IV

VAPOR PRESSURE TABLE

Temperature Centigrade	*Pressure Millimeters*	*Temperature Centigrade*	*Pressure Millimeters*
0	4.6	99.40	744.0
10	9.0	99.48	746.2
20	17.5	99.55	748.0
30	32.0	99.63	750.5
40	55.3	99.70	752.2
50	110.2	99.78	754.7
60	149.5	99.84	756.3
80	354.2	99.92	758.0
90	525.0	100.00	760.0
99.03	734.0	100.07	762
99.10	736.0	100.15	764
99.18	738.5		
99.25	740.0		
99.33	742.5		

VAPOR DENSITY TABLE

Temperature		*Water in Grams*	*Temperature*		*Water in Grams*	*Temperature*		*Water in Grams*
C.	*F.*		*C.*	*F.*		*C.*	*F.*	
0	32	4.84	14	57.2	11.96	27	80.6	25.49
1	33.8	5.13	15	59.0	12.71	28	82.4	26.93
2	35.6	5.54	16	60.8	13.50	29	84.2	28.45
3	37.4	5.92	17	62.6	14.34	30	86.0	30.04
4	39.2	6.33	18	64.4	15.22	31	87.8	31.70
5	41.0	6.76	19	66.2	16.14	32	89.6	33.45
6	42.8	7.22	20	68.0	17.12	33	91.4	35.27
7	44.6	7.70	21	69.0	18.14	34	93.2	37.18
8	46.4	8.21	22	71.6	19.22	35	95.0	39.18
9	48.2	8.76	23	73.4	20.35	36	96.8	41.30
10	50.0	9.33	24	75.2	21.54	37	98.6	43.50
11	51.8	9.93	25	77.0	22.80	38	100.4	45.80
12	53.6	10.57	26	78.8	24.11			
13	55.4	11.25						

1 cubic meter = about 1.3 cubic yards.

For example, at 10°C. the saturation density of water vapor is 9.33 grams.

APPENDIX V

INTERNATIONAL ATOMIC WEIGHTS
1938

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	Symbol	Atomic Number	Atomic Weight		Symbol	Atomic Number	Atomic Weight
Actinium	Ac	89	227	Manganese	Mn	25	54.93
Actinon	An	86	222	Masurium	Ma	43	?
Alabamine*	Am	85	?	Mercury	Hg	80	200 61
Aluminum	Al	13	26.97	Molybdenum	Mo	42	95 95
Antimony	Sb	51	121 76	Neodymium	Nd	60	144 27
Argon	A	18	39 944	Neon	Ne	10	20 183
Arsenic	As	33	74 91	Nickel	Ni	28	58 69
Barium	Ba	56	137 36	Nitrogen	N	7	14.008
Beryllium	Be	4	9 02	Osmium	Os	76	190.2
Bismuth	Bi	83	209 00	Oxygen	O	8	16.0000
Boron	B	5	10 82	Palladium	Pd	46	106 7
Bromine	Br	35	79 916	Phosphorus	P	15	31 02
Cadmium	Cd	48	112 41	Platinum	Pt	78	195 23
Calcium	Ca	20	40 08	Polonium	Po	84	210?
Carbon	C	6	12 010	Potassium	K	19	39 096
Cerium	Ce	58	140 13	Praseodymium	Pr	59	140.92
Cesium	Cs	55	132 91	Protactinium	Pa	91	231
Chlorine	Cl	17	35 457	Radium	Ra	88	226.05
Chromium	Cr	24	52 01	Radon	Rn	86	222
Cobalt	Co	27	58 94	Rhenium	Re	75	186 31
Columbium	Cb	41	92 91	Rhodium	Rh	45	102 91
Copper	Cu	29	63 57	Rubidium	Rb	37	85 48
Dysprosium	Dy	66	162 46	Ruthenium	Ru	44	101.7
Erbium	Er	68	167 2	Samarium	Sm	62	150.43
Europium	Eu	63	152 0	Scandium	Sc	21	45 10
Fluorine	F	9	19 00	Selenium	Se	34	78 96
Gadolinium	Gd	64	156 9	Silicon	Si	14	28 06
Gallium	Ga	31	69 72	Silver	Ag	47	107 880
Germanium	Ge	32	72 60	Sodium	Na	11	22.997
Gold	Au	79	197 2	Strontium	Sr	38	87.63
Hafnium	Hf	72	178.6	Sulfur	S	16	32 06
Helium	He	2	4.003	Tantalum	Ta	73	180 88
Holmium	Ho	67	163 5	Tellurium	Te	52	127 61
Hydrogen	H	1	1.0081	Terbium	Tb	65	159 2
Illinium	Il	61	?	Thallium	Tl	81	204 39
Indium	In	49	114 76	Thorium	Th	90	232 12
Iodine	I	53	126 92	Thulium	Tm	69	169 4
Ionium	Io	90	?	Tin	Sn	50	118.70
Iridium	Ir	77	193.1	Titanium	Ti	22	47 90
Iron	Fe	26	55.84	Tungsten	W	74	183.92
Krypton	Kr	36	83 7	Uranium	U	92	238.07
Lanthanum	La	57	138 92	Vanadium	V	23	50.95
Lead	Pb	82	207 21	Xenon	Xe	54	131 3
Lithium	Li	3	6 940	Ytterbium	Yb	70	173.04
Lutecium	Lu	71	175.0	Yttrium	Yt	39	88.92
Madavium*.	Md	87	?	Zinc	Zn	30	65 38
Magnesium	Mg	12	24.32	Zirconium	Zr	40	91 22

* Discovery uncertain.

APPENDIX VI

The Theory of Relativity

Although it is doubtful whether a discussion of the theory of relativity has a place in a survey course in science, the subject is of such intense interest among all types of people that a brief description of it may not be out of place. At the outset, it must be emphasized that an elementary treatment of the subject is, of necessity, rather inaccurate.

The history of relativity of motion dates back to the time of ancient Greece. Even in those times men discussed questions of "absolute" time and space. They knew that in order to completely locate any moving object, they must consider both its position and the time at which it was observed. If an automobile is sighted at a certain street corner at 10 A.M. we have set up certain reference lines and times. If we wish to locate an airplane we can indicate its latitude and longitude and the time that we saw it.

Perhaps it may be said that modern relativity originated in discussions of the ether, that mysterious medium which was supposed to propagate electromagnetic waves through space. During the 19th century, scientists were certain of the existence of the ether and, as a result, many experiments were performed in an attempt to study its properties.

Since the universe was supposed to be filled with ether, men wondered what happened when the earth revolved around the sun. Did the earth swim in the ether like a wooden ball in water? If so, did it drag the ether along with it to some extent, in the same manner that the ball would drag the water in its wake. Did the ether retard the motion of the earth?

Michelson and Morley,* in 1887, attempted to answer these questions by performing an interference experiment with light. Although the experiment was carried out with extreme care, they could not find a relative motion of the earth and the ether. At about the same time Kaufmann found that the mass of an electron

* An American chemist.

seemed to increase as its speed became very rapid. This was a startling discovery.

Relative Motion. To say that a car is in motion is to assume that the pavement is at rest. If the pavement and all the surrounding objects were moving with the same speed as the car, we could not be certain that the car was in motion at all. All motion is relative. We walk about on the earth, the earth moves about the sun, the sun moves relative to other stars. Because all motion is relative, discussions of motion are difficult to understand. The human mind does not readily adapt itself to think in these complex terms.

In 1905, Einstein, at one bold stroke, discarded much of the complexity by assuming that the laws of nature were always the same (invariant) no matter where the observer happened to be. This means that a relative motion of the observer does not affect the laws of nature. We shall not confuse the reader by a discussion of the mystifying space-time relations which are involved in the Special Theory of Relativity. Suffice to say that one consequence of the theory is that mass and energy are interchangeable. Einstein concluded that a body, even when at rest, has rest energy because it has mass. Energy and mass are possibly different manifestations of the same fundamental quantity.

The theory gives rise to the famous equation E equals MC^2, which we used in Chapter 2 in connection with the Einstein explanation of the cause of the sun's heat.

Some years later Einstein set forth the General Theory of Relativity. In this expanded theory he attempted to solve the age-old mystery of the gravitational force which attracts all bodies in the universe. In this theory, Einstein assumed that gravitational force could be explained on the principle that the body, which seemed to be exerting gravitational force, was really being accelerated in "world" space. If the room in which we are seated is being accelerated in a region in which there is no gravitational force, an apple dropped from the hand would seem to fall to the floor. We would say that it was pulled downward by gravitation. Actually, there may be no force and the apparent downward motion is really an upward motion of the room. We

rise to meet the apple. According to this principle we cannot distinguish gravitational force from an acceleration. The theory indicated that, because of this acceleration, a ray of light passing close to a large body such as the sun would appear to be deviated from a straight line. In order to check this theory it is necessary to use the time when the sun is in eclipse. At such times the light from stars which are almost directly in line with the sun can be seen. Various eclipse expeditions have studied this effect and it seems that the deviation actually exists.

One of the difficulties that the layman experiences in attempting to understand relativity is the type of reference line used by Einstein. Instead of using the usual Euclidean coordinates he uses the Gaussian system. All Gaussian coordinate systems are equivalent when we discuss the laws of nature.

Probably the most speculative part of the theory of relativity is the discussion on the size of the universe. Modern astronomy has proved that there are stars in nebulae millions of light-years distant. Naturally, we ask about the size of the universe. Does it have a boundary or is it infinite? If it has a boundary, what is beyond? Einstein by his description of curved space comes to the conclusion that if a "straight" line were drawn out into space, it would finally extend back to the starting place from the opposite side of the universe. We might use the homely illustration that had we the ability to see far enough up into the sky we could see the backs of our heads. Perhaps two different nebulae are simply different views of the same one.

The Einstein theory, controversial and difficult though it is, has been the means of opening great new fields of thought. We believe that mass is an electromagnetic quantity. The laws of relativity are in every day use in scientific computation. Nevertheless, since the new ideas of Einstein change but little the laws of the universe as stated by Newton and Kepler, the man on the street has no special need for understanding the principles. Perhaps he may get some satisfaction by attempting to read some of the many popular expositions of the subject. We must however appreciate the genius of Einstein in formulating the stupendous principle.

REVIEW QUESTIONS

Note. Some of these questions necessitate reference reading.

CHAPTERS 1–7

1. Why do some stars rise and set?
2. Why do some stars never set?
3. A star rising at 7 P.M. April 1, will rise at what time on June 15?
4. Do all parts of the earth have a full moon during the same 24 hours?
5. Would it be correct for the people of Chile to say that winter was due to the fact that the sun was furthest from the earth?
6. What is the cause of twilight?
7. Would the earth have tides if there were no moon?
8. What is the cause of a ring around the moon?
9. Many telescopes are placed on mountains. Why?
10. What is meant by a light-year?
11. Most modern telescopes use a concave mirror rather than an objective lens. Why?
12. What is meant by the Vernal Equinox? Where is it?
13. What reasons did Galileo give for his belief that the sun rather than the earth is the center of the solar system?
14. Describe some methods by which astronomers measure great distances.
15. What is the Milky Way?
16. Some nebulae are believed to be millions of light-years distant. How do we know this?
17. If the sun were to become cooler, how would this affect our habits of living?
18. Calculate the times required for light to reach the earth from Jupiter and Neptune.
19. Is the sun a gas or a liquid?
20. Why do we not use the Nebular Hypothesis?
21. How was Pluto discovered?
22. How do we know that no air exists on the moon?
23. What planets may have life? Explain.
24. Why are "shooting stars" hot?
25. What proofs have we that the earth rotates on its axis?
26. Does the sun ever reach the zenith at latitude 45° North? At longitude 75° West?
27. Are tides ever observed in solid rock?
28. Distinguish between rotation and revolution.
29. How rapidly does the earth rotate?
30. What is the Ecliptic? Where is it?

31. Why do we see only one side of the moon?

32. It is often said that the "planets nod to each other as they pass." What is meant?

33. List, from the references, some other methods for measuring the velocity of light.

34. Why do stars "twinkle"?

35. Why is the sun red at evening and yellow at noon?

36. Why do stars differ in color?

37. How can we prove that the sun rotates?

38. What is the Zeeman effect?

39. List the planets in order of distance from the sun.

40. We see slightly more than half of the moon's surface. Why?

41. What are novae?

42. The diameters of several stars have been measured. Find out how this was done.

43. What is the difference between a constellation and a cluster?

44. What is a galaxy? A star universe?

45. List ten constellations that you have learned to know.

CHAPTERS 8–12

1. The statement is often made that the equinoxes are times of stormy weather. Is this true?

2. Does carbon dioxide benefit man? Explain.

3. Could we live without nitrogen?

4. Just why do we think the earth is very old?

5. Why is pure aluminum not used in structural work?

6. What is meant by the term "steel"?

7. How can we measure the thickness of the atmosphere?

8. What is to hinder a rocket from leaving the earth and moving out into space?

9. What are the causes of volcanoes?

10. How can we explain the presence of coal in Antarctica?

11. On a hot day a fully inflated automobile tire sometimes leaves the rim. Explain.

12. Just what does a barometer measure?

13. Why does the air become warmer when snow is falling?

14. What is the difference between a tornado and a cyclone?

15. What causes "sea breezes" at the seashore?

16. How can the Weather Bureau predict weather?

17. Why do we believe that the centrosphere contains mostly iron and nickel?

18. Name the five eras of geological time.

19. In what era did man first appear?

20. Make a list of the most important features of each era.
21. In what era did life first appear?
22. Is a vacuum empty of all material?
23. What were the achievements of Lavoisier?
24. Is gasoline a compound? Explain.
25. How are limestone caves formed?
26. Give two important uses of clouds.
27. What causes winds to spring up?
28 What is the cause of highs?
29. Distinguish between rocks and minerals.
30. Describe the manufacture of glass.
31. What is meant by Bessemer steel? Open hearth steel?
32. How does hardness differ from brittleness?
33. Draw a diagram of the forces on an airplane.
34. What is meant by the statement "Nature abhors a vacuum"?
35. Describe an aneroid.
36. The cap on a gasoline tank has a hole in it. Why?
37. Describe a siphon.
38. Why do people cover plants on cool fall evenings to protect against frost?
36. Why does a swimmer who stays in water for several hours sunburn badly?
40. Why does one sunburn badly on cold mountain tops in summer?
41. If a pinhole were made in the top of a barometer, would the reading be affected?
42. Why is mercury better than water for barometers?
43. Why can we suck soda through a straw?
44. Explain how a balloonist descends.

CHAPTERS 13 AND 14

1. Are cathode rays the same as X-rays?
2. For what is Millikan noted?
3. What does the word, Quantum, mean to you?
4. Does every object possess electrons?
5. What are the two theories of light propagation? Explain the differences between them.
6. What is the function of a cyclotron?
7. What is the nature of alpha, beta, and gamma rays from radium?
8. What are some of the uses of X-rays?
9. What is meant by atomic number?
10. What are molecules? atoms?
11. What is a Crookes tube?
12. Diagram a Coolidge tube?

13. Why are X-rays more dangerous to the body than ultra-violet rays?
14. What is a line spectrum? A continuous spectrum?
15. What is a neutron? A positron?
16. What are the dangers of radium?
17. Describe the appearance and properties of radium and polonium.
18. What is "artificial radioactivity"?
19. How do X-ray operators protect themselves?
20. What is the difference between radium and uranium?

CHAPTERS 15–20

1. Do all bodies really fall with the same acceleration?
2. Gravitation helps to keep the moon in its orbit. Explain
3. Would a man weighing 150 pounds on the earth weigh more on Mars?
4. In what direction does the mud thrown from an automobile wheel travel?
5. Does a body ever lose its weight?
6. Why not replace a fuse plug by a penny?
7. In what units is electrical energy measured?
8. Name 4 conductors and 5 insulators.
9. Why does a compass point north?
10. How does a bar magnet differ from an ordinary iron bar?
11. Why do we use high voltage on long distance transmission lines?
12. Of what use is a photocell in sound movies?
13. How is the temperature of the body kept constant?
14. Is the law of conservation of energy always true?
15. Can a temperature exist which is lower than $-453°F.$?
16. Will boiling water always injure the skin?
17. Why is dry ice called "dry"?
18. Why are we sometimes chilled by a fan?
19. For what was Marconi famous?
20. Why does a motion picture machine jerk just 16 pictures per second across the screen?
21. What is meant by weight?
22. Why is skidding a feature of rapid turning?
23. Name and describe the different types of coal.
24. Why do we prefer Pyrex to ordinary soda glass for many purposes?
25. On high mountains, food will not cook if the water is boiled in open vessels. Explain.
26. Why is a perpetual motion machine improbable?
27. Make a list of energy transformations in the home.
28. Why do we not use a carburetor on a Diesel engine?
29. Can you explain why we see objects erect, although the image on the retina is inverted?

30. Do you expect that commercial television receivers will be simple in construction?

31. A 1.5 volt dry cell is connected to an unknown resistance and the current is found to be 18 amperes. What is the value of the resistance? If the current flows for one minute, how much heat is produced?

32. Why not use a doorbell transformer as a home-lighting transformer?

33. What does 85°F. represent in Centigrade?

34. Inasmuch as perpetual motion is impossible, why does the earth rotate?

35. What is the principle of a wedge?

36. Why do we shift gears into low when we climb a hill?

37. An engine is hauling 100 tons of coal each hour from a mine 300 feet deep. What is the Horse Power?

38. Can we "let in the cold"?

39. Can one cook potatoes more rapidly by turning up the gas so that the water boils vigorously?

40. Why do clothes "freeze dry" on a cold windy day?

41. Why is sawdust used in ice houses?

42. Why do we find snow on the mountain tops in summer?

43. Why do we "defrost" mechanical refrigerators?

44. Is a "magnetic" person really magnetic?

45. For what was Oersted noted?

46. A long wire carrying current is in a north-south line. What will happen to a compass needle placed under the wire?

47. Why can birds sit safely on a high tension wire?

48. What is a line of force?

49. How is "polaroid" formed?

50. A hydraulic press has a piston one inch in diameter. When 10 pounds are applied to this piston a force of 5000 pounds is exerted. What is the diameter of the large piston?

51. Why are wireless waves called Hertzian waves?

52. Investigate the radio receiver in your home. What type is it?

CHAPTERS 20–27

1. Blood corpuscles are never placed in distilled water for fear they will burst. Explain.

2. Can the buoyant force ever exceed the weight of the body immersed?

3. If a ship sails from the ocean into a fresh water lake will the water line on the ship rise or sink?

4. What is iatro-chemistry?

5. What would you eat to secure protein? fat? carbohydrate? vitamin C?

6. Consult the atomic table in the Appendix and list the elements which you know. Also list familiar properties of each one.

7. Describe the theory of ionization as stated by Arrhenius.

8. Describe the various vitamins.
9. What is electrolysis? electrode?
10. List the chemical changes which commonly occur in the home.
11. What is osmosis?
12. What is a cathode? An anode?
13. Describe the principle of dissociation.
14. What is meant by the statement that soap is 99% pure?
15. List some synthetic dyes and perfumes. Attempt to find the chemical names for them.
16. How would you identify a liquid as a solution or colloid?
17. List some explosives and give their properties.
18. How would you remove an ink spot?
19. Why are eyes blue?
20. Make a list of acids, bases, and salts that you know.
21. How does your community get its water?
22. How is the water purified?

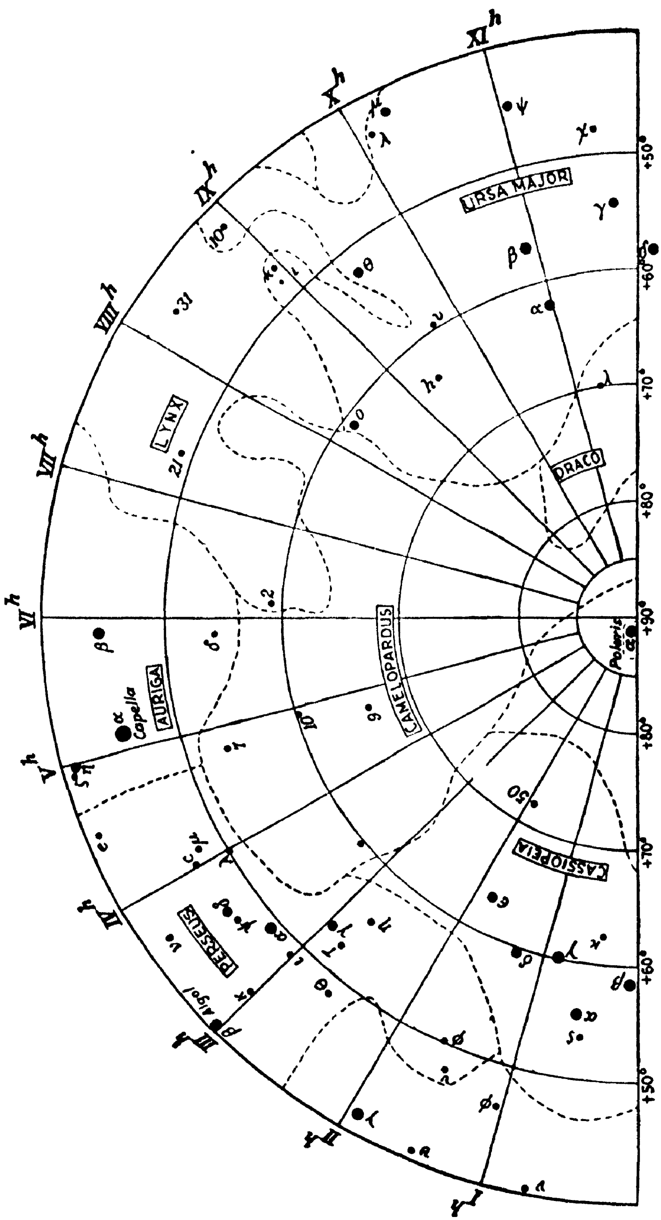

CHART 1. The north circumpolar group. (*Fath's Astronomy*, *McGraw-Hill Book Co.*)

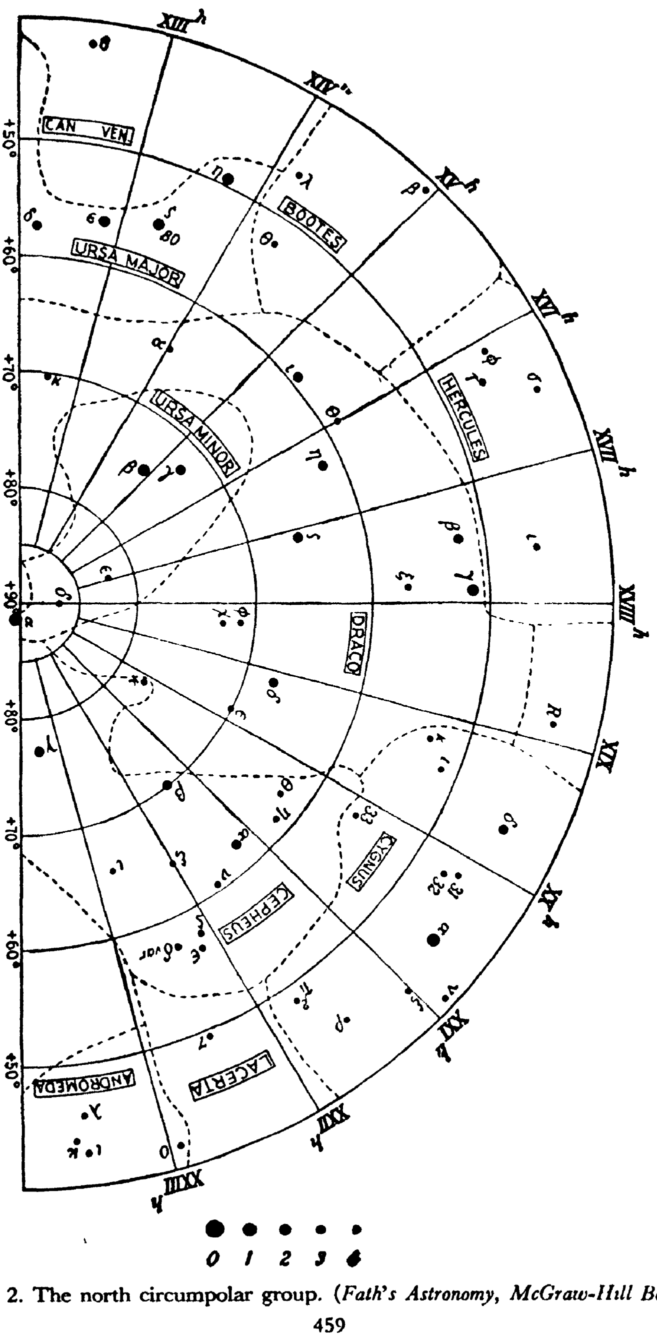

CHART 2. The north circumpolar group. (*Fath's Astronomy, McGraw-Hill Book Co.*)

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